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THE

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OF THE
LOCATION OF RAILWAYS

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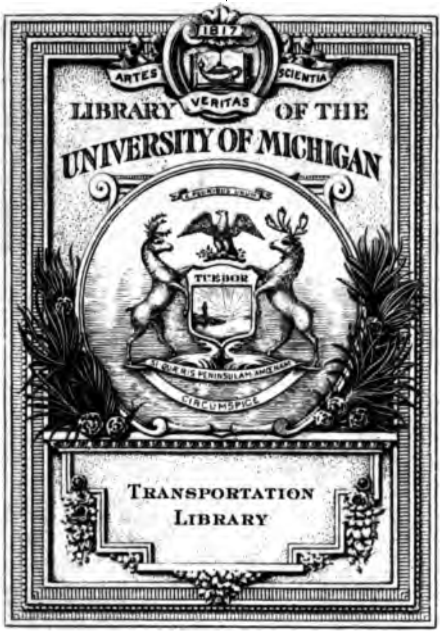
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THE

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OF THE

LOCATION OF RAILWAYS.

THE
ECONOMIC THEORY
OF THE
LOCATION OF RAILWAYS.

AN ANALYSIS OF THE CONDITIONS WHICH GOVERN
THE JUDICIOUS ADJUSTMENT OF GRADIENTS,
CURVATURE AND LENGTH OF LINE
TO EACH OTHER AND TO THE
CHARACTER AND VOLUME
OF TRAFFIC.

BY

ARTHUR M. WELLINGTON,
CIVIL ENGINEER.

PUBLISHED BY
THE RAILROAD GAZETTE, 73 BROADWAY, NEW YORK.

1877.

Entered according to Act of Congress in the year 1877, by
ARTHUR M. WELLINGTON,
in the Office of the Librarian of Congress, at Washington.

E. P. COBY & CO.,
PRINTERS,
95 WILLIAM ST., N.Y.

Transport.

TO THE
GREAT MEN OF
A FORMER GENERATION,
WHO ORIGINATED THE AMERICAN
RAILWAY SYSTEM, THIS ATTEMPT TO IM-
PROVE UPON THEIR PRACTICE IS ADMIRINGLY
INSCRIBED, IN TOKEN OF RESPECT
FOR THEIR FAR-SIGHTED
SAGACITY AND STILL
UNEQUALLED
SKILL.

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INTRODUCTION.

The investigation of which this volume is the fruit had its origin some two years since in the preparation of a few notes for an anticipated location, and has since gradually expanded from small beginnings into a single magazine article, a short series of paper, and at last into a volume. Even the latter has been extended far beyond the writer's original intention, by the close and, it is to be feared, tedious attention to detail which he found continually more needful; and it is kept within its present proportions only by excluding considerable matter and superficially considering or neglecting altogether a number of subjects which the writer deems of real importance for the correct conduct of location. He is led to do so, however, by a clear comprehension of the fact that there may probably be few to agree with him. Among these subjects he would especially note the adjustment of motive power to the grades and conditions of traffic: a widely neglected question of the greatest importance, which should be settled before driving a stake. Most of the articles have been in type, moreover, before the next one was on paper. The faults inseparable from such a process of development are unpleasantly evident to the writer, as they must be to every reader. In the improbable contingency that the sale of this volume should justify a thorough revision at some future day, he hopes to produce one more in keeping with the professional interest and importance of the subject, by rectifying the faults of omission and commission which he clearly perceives.

The writer does not intend to imply, however, that he has fallen into unacknowledged errors of fact or theory. All known errors have been frankly corrected as soon as discovered, and it is but just to add that much of the omitted material would strikingly confirm the correctness of opinions and estimates originally based of necessity on somewhat dubious premises. For such other errors as may probably exist, the writer can only hope that they will be regarded with that leniency which an exploration of a neglected field of labor may fairly ask. For such the present volume is, with all its imperfections. A recognition of the value of previous discussions of the same subjects would be a more welcome duty, but the writer deems it but simple justice to himself and his readers to declare frankly that, so far as his knowledge extends and he is competent to judge, all of the few existing discussions of the various leading topics of this volume are so superficial or so imperfect in method that they have little or no value as a guide for location. Some of them express correct views, and some of them will sometimes give correct results; but none of them are *trustworthy*, and several of those which are given under distinguished names are incredibly defective. The various problems of location, in fact, have been discussed or neglected by technical writers with an airy lightness which would convince an unskillful reader that they were either too simple, or too unimportant, or too well understood, for any careful analysis. And yet there is no field of professional labor in which a limited amount of modest incompetency, at $150 a month, can set so many shovels and locomotives and machine shops at work to no purpose whatever; while at the same time many of the problems connected with sound location—problems of high financial importance, which the writer has but rudely touched upon—would seem sufficiently intricate to tax the reasoning and analytical powers of the keenest intellects. It is impossible to be sure about this, however, for they do not appear ever to have tried.

Now, the plain truth of the matter is, that, as a natural consequence of this general negligence, *all* our railways are uneconomically located—most of them in respect to their general route and system of gradients, and *all* of them in respect to the minor details of alignment, and in many cases these errors are shockingly evident. A statement which is apparently so egotistical is made with reluctance, but, as a result of the present investigation, the writer is profoundly impressed with the truth of the fact and its calamitous consequences. The probable exceptions of which he has no knowledge are only sufficient to prove the rule, and he entertains no doubt whatever that if the railways of the United States were to be rebuilt on the most judicious location, their cost would not be more than two-thirds as much (so far as affected by line and grades, not including any economy from "cheap and nasty" construction), and freight could then be moved over them for about half the present cost, if we grant the corollary of motive power well adjusted to the grade and conditions of traffic. Perhaps the nearest approach to a well-located railway among the considerable number with which the writer is more or less acquainted, is to be found—after excepting a few lines for which nature not only fixed the route, but staked it out—in parts of the Baltimore & Ohio, the Pennsylvania and the Erie; these railways being selected, not because they are great roads with which the writer is familiar, but because they were located by great men. Each of them has grave errors of location, if the writer be competent to judge, but in comparison with any one of them great numbers of our wretched modern specimens, which ought to be *better* located, are inferior beyond all comparison. Let us take one modern example, selecting it because we have given sufficient attention to it in this volume to justify our statements, although it is otherwise exceptional only in its excellence. This railway, among other costly work, has 27 tunnels on its line; and now that they are all completed not the Pyramid of Cheops was a more needless waste of human labor: For the majority of them were necessitated by a fanciful and unscientific adjustment of curvature and grades which has not lessened by a dollar the cost of moving freight, but on the contrary has probably increased it; and of those which are left the longest was necessitated by seeking for a low grade when a higher one would have given equal operating advantages; and any which are still left, and two or three dozen more, would have been paid for by the saving which might have been effected by the adoption of a totally different route;—and this *without considering* the fact that freight could be moved over the cheaper line for but little more than two-thirds of the cost over the costly line. And yet this line is no isolated example, but on the contrary is in many respects an exceedingly creditable specimen of modern railway construction.

Now, to a reflecting mind, there is something almost pitiful in the waste of human labor enforced by such costly blundering as this. It is this kind of thoughtless carefulness, far more than deliberate and conscious improvidence, which keeps the world poor. And more than this, the loss from bad railway location has risen to such gigantic proportions that it is no longer a mere question of finance, affecting a few individuals, but one of grave importance in political economy. For the transportation tax is the most onerous under which the world labors, and it is an understatement to say that the *needless* portion of this tax is greater than all our political burdens, while at the same time the skill shown in railway location—on which the whole question of operating economy depends—is deteriorating rather than advancing. It is a blind perception of this fact which keeps life in the quack remedy of the narrow-gauge. To quote from the "Autocrat of the Breakfast-Table," when professional men fall into hopeless intellectual lethargy, "they must be given over to the scourgers, who like their task, and get good fees for it. * * * And so, while this solemn farce is going on, the world over, a harlequin pseudo-science has jumped upon the stage, whip in hand, with half-a-dozen somersets, and begun laying about him." Now, the NARROW-GAUGE is the harlequin which has jumped upon the engineering stage in this farce of railway economy, and it has much truth on its side, and is doing an important work. To quote again from our wisest of humorists: "A pseudo-science does not necessarily consist *wholly of lies.* It may contain many truths, and even valuable ones. The rottenest bank starts with a little specie. It puts out a thousand promises to pay on the strength of a single dollar, but the dollar is very commonly a good one. The practitioners of the pseudo-sciences know that common minds, after they have been baited with a real fact or two, will jump at the merest rag of a lie, or even at the bare hook." The service of the narrow-gauge lies in this: that by casting aside *all* precedents, the good and bad alike, it is compelling engineers to *think.* Gradually they will awaken to see that the narrow-gauge advocates are right in demanding light engines and a light line for a light traffic, and the narrow-gauge proper will then die a natural death. For there exists no reason whatever why railways of common gauge should not be built to accommodate one train daily for but little more than the cost of a good turnpike, and yet move freight and passengers with marked economy; if engineers would only *study* the relations of cost to value which we have so superficially and imperfectly discussed, and thoroughly understood them. But the trouble is that, almost without exception, they "survey" and build their railways without the least investigation of the extent and character of probable traffic, or of the true economy of alignment, and regulate the character of their line solely (or mainly) by the length of the company's purse. Because it is economy for some great trunk line to spend large sums for trivial improvements, they conclude that *they* should have them, in order to move freight *cheaply.* The natural result follows: the line is forthwith swamped by its capital account; the process being usually hastened by a lot of locomotives ordered heterogeneously of some great shop which builds them by the hundred and ships them to order.

It is *this* that ruins railways of light traffic and eats them up alive, and not the dead weight hauled.

Now it is time that it should be generally recognized that the location of *any* railway, long or short, cheap or costly, is an intricate and difficult problem of original design, requiring patient investigation before setting a stake—and before setting each stake. It is simply *impossible* to make even a decently passable location without doing this, just as it is impossible to lay down the line on paper without the aid of compass and straight-edge. A man may learn by practice to sketch in a map without instrumental aid which shall not be glaringly defective on chance inspection, and a man may also learn by practice to make a location which shall not look very bad from the rear end of a palace car; but no man—were it Giotto himself—will ever make a useful working map by sketching in his curves free-hand and guessing at his angles, nor will the oldest and ablest engineer ever guess at a respectable alignment when it is tested be economic laws; and they do not now do so. In the care taken in this respect we are not advancing beyond, but rather falling below, the standard set up forty years ago, when the art of designing railways started out in this country with such brilliant promise. The works of Latrobe and Jervis and Thomson and Whistler show a truly remarkable ability, considering their early day, and bear the clearest marks of original and self-reliant thought; but the great men of that earlier day have no successors; for we have done nothing but copy them ill ever since, and a copyist is not a successor. We copy their *errors*, but we do NOT copy that admirable habit of personal investigation and far-sighted intellectual courage which *created* precedents, and has made the work of their hands—in despite of many faults—the high-water mark of American locating skill. For example: the location of the Baltimore & Ohio Railroad was a real masterpiece, but the confessed copy of it on the Central Pacific Railroad is, in an economic point of view, an entire abortion. A true comprehension of the science of gradients would have shown that, under the different topographical conditions, the long developments in the mountains to reduce grades below 105 feet per mile were unjustified by considerations of operating economy, even if they had not increased the cost of construction, as they did enormously; and it is only a partial excuse that the line was primarily located by several hundred engineers *ex officio* with an Act of Congress. In the same way, the fact that some of our earlier engineers failed fully to appreciate the economic mistake of piling sharp curvature on top of an arbitrary maximum grade has cost the country uncounted millions ; for their oversight has been thoughtlessly copied ever since on the great majority of railways.

This, however, is not the place to discuss particular errors, and the writer only desires to attract attention to the calamitous effect of our present carelessness. Railway location at the present day is almost wholly a matter of personal prejudice and *whim*, as unreasoning and unscientific as the famous location of the Czar Alexander from St. Petersburg to Moscow. The engineer who has grown up in the school of sharp curves and high gradients is *always* ready to use them; the one who hasn't, looks upon a 6° 30′ curve as an expedient of the most desperate character. Yet neither of them can give any good reason for the faith that is in him, for he has no very clear idea as to *how much* he may afford to spend to avoid the one or the other. A curious proof of this fact might be found in the readiness with which tunnelling is resorted to by different engineers, under substantially the same circumstances. As another: the writer once knew an engineer of fair ability, now dead, who would incur considerable expense rather than introduce a break of grade on a tangent—*where it could be seen!* If the flippancy may be pardoned, he ought to die; and yet it is to be feared he is not alone in his whimsey.

Another inevitable consequence of such general neglect is that this intricate science of design has been degraded in popular esteem, and even in the minds of engineers who ought to know better. In former times the ablest engineers gave personal and unremitting attention to the work of location, but we have changed all that at the present day. As soon as a young man has acquired some facility in transit work and has some glimmering notion that curves and grades are very objectionable evils—or are *not* very objectionable evils, depending on whom he "ran transit" for—he is forthwith a *locating engineer*, and he is such in fact in so far as this, that further practice will teach him nothing. For after making one or two surveys he will have mastered the mechanical process of handling a party, and begin to look down on the work of location—because he knows nothing about it. His work is the dead corpse of location, beginning and ending in the transit. If he is a rising man, he will soon find some other young man to take his place in the field, and do the really *important* work, and very probably begin that vicious system of office location from contour maps which has ruined the alignment of so many railways. Now all this is especially calamitous, for it is almost a certainty that any one who has not a thorough *theoretical* as well as practical knowledge of location will fail entirely to catch the governing features of the region traversed, and find the line which has probably been lying there since time began. The instances are almost innumerable where young men—and old men—of this class have run over and under and across a line of the highest operating value, and turned in a costly and miserable line at last. And the contour-map system does not help this evil, even in the hands of a thoroughly capable engineer; for the contour-map is simply a device for doing ill in the office the simplest part of the work, viz., the first approximation to the adjustment of the line in detail; and its most effectual office is to deaden the perceptive faculties of the engineer in charge of the party and transform him into a mere machine. Of what value is a contour-map of an ill-judged line? The truly *difficult* part of location is the selection of the general route and the final ultimate perfection of its adjustment in detail; and the engineer who can do *this* work well will thank no one for the rude assistance of a contour-map location, made without that detailed familiarity with the ground which is gained by tramping over it. In fact, he will approximate to the detailed alignment quite as well and as rapidly without any such assistance, simply by feeling his way upon the ground, profile in hand, and his party behind him, and guided by a few notes from a rough plot. Nor will such an engineer, if he have a true feeling for the dignity and importance of his work, be content with making some contour-map guesses to be tested by less-skilled subordinates. If he is to interfere in any way and his judgment have any value on paper, it is worth more upon the ground—and there is where he ought to be. He will detect more possibilities while sitting on the fence in apparent idleness than by the longest study of maps, and however long his experience or brilliant his ability, he can at no time in his professional career have more important financial interests depending on a chance inspiration. It should be more generally recognized that the place for the ablest engineers which money will command is not in the office or on construction, but in the field at the head of the locating party.

A large part of this evil is not the fault of engineers, but is due to the fact that the financial loss from bad location is too distant and indirect to excite an amateur's apprehension, and every officer of a railway, from the president down, is an amateur engineer; having all the amateur's fondness for "meddling and muddling" in *unimportant* matters, and all the amateur's reluctance to recognize anything as important which he does not himself understand. The fatuity displayed by the average railway official in this way quite passeth understanding. He will pay lavishly for his attorney's skill in trickery; he will even pay respectably for the manager's skill in dealing with men and with things; but he will neither pay for nor believe in that vastly more needed skill of the engineer in dealing with abstract physical and mechanical laws, and in determining the financial meaning of their relationship to involved and contradictory facts. For this work he neither seeks for nor will he tolerate anything more than a hand to execute; and the law of supply and demand gives him just what he asks for. Especially is this true in location. On the great majority of railways surveys are intrusted without the slightest uneasiness to the first graduate of the transit who comes to hand; but when he has *completed* his work, and construction is to begin, *then* we may behold an extraordinary and amusing spectacle. Then we may see half a dozen business men, who probably show some common sense in their own affairs, scouring the country with a lantern to find a constructing engineer of the greatest possible ability at the smallest possible salary—to do what? To pay over the money which is *already spent;* to pare and shave at the cost of work which might have been avoided altogether; to *build* the complicated mechanism for which they have just permitted Thomas, Richard and Henry to make designs and working drawings. This kind of folly has its root in some of the deepest foibles of human nature, and it will probably never be done away with altogether; but it is to be hoped that railway companies may more generally appreciate the fact that their road is built *and equipped* in the brain of their locating engineer—if he has any; and that if his work be ill done, all the engineers in Christendom have done little to remedy his errors, though they execute his folly for half its proper cost. The truth is, in fact, that ordinary constructive engineering is a much lower branch of professional labor and makes far less drafts on those qualities of mind which make the engineer. But massive piles of dirt and stone and iron are visible evidences of *power* which impress the imagination of the wayfaring man as equal evidences of skill; and hence it is not wonderful that the ability of engineers is more generally estimated by the grandeur of the works they have executed than by those which they have avoided.

The writer earnestly hopes that this little volume may help an occasional reader to a clearer understanding of the profoundly important questions so imperfectly discussed in it. He has spoken severely of American railways, and only of them, because he has written for Americans; but he deems it but just to add that, so far as he is competent to judge, American railways are by far the best located in the world. It is the complacent fashion of foreign critics to assume that American railways cost less because they are of inferior construction; and doubtless this judgment has had and still has much truth. But the fact is that the *main* cause of the excessive cost of English and other foreign railways is, not that they have better bridges, or wider cuts, or thicker ballast, but that they are located with greater ignorance of and contempt for economic laws. It may be hardly fair to criticise English railways proper very severely in this respect, as they were built at so early a date and with such great difficulties as to right of way; but for errors committed in other parts of the world English engineers are plainly responsible, and it is almost painful to consider the enormous capital accounts with which they are saddling their unfortunate colonies, for railways most wretchedly designed. This being so, it is not strange that the narrow-gauge quack remedy has a more numerous following in England than here; for the patient in most desperate condition, and most ignorant of the true nature of his complaint, is always the readiest to dose himself with nostrums. But there is something truly ludicrous in the fact that English engineers have favored the inconvenient narrow-gauge for India as a measure of *economy*, and have then proceeded to locate their narrow-gauge lines with such blind contempt for economic laws that they are costing far more than a broad-gauge railway would, if located and equipped in true conformity with the conditions of traffic. The writer is speaking by the card in this statement and is able to substantiate it, but it is not probable that his voice will reach to so great a distance, and he has therefore omitted to do so. If, however, a stray copy of this volume should chance to fall into the hands of an engineer at the Antipodes, he is asked carefully to consider whether the *true* cause of the excessive cost of his railways, over that of the American railways which he looks on as awful examples, be not that he is more apt to imitate Mr. Toodles by buying a lot of costly luxuries which he does not need; in other words, if he does not more often spend £1,000 for some fancied improvement which does not save £10 a year in operating expenses.

If in any respect the writer counts upon the approval of every reader, it is in the detailed and copious index which accompanies this volume. Nearly all technical works are deficient in this respect, and notably the various pocket books in a marked degree. In the writer's view it is an outrage upon some hundreds or thousands of purchasers that the small labor of a perfect index to a miscellaneous collection of facts should be begrudged them. Every isolated fact or statement in this volume, however incidental, which it may possibly be required to find, is instantaneously available. A good index, it is true, was more than ordinarily required for the present volume on account of its fragmentary disarrangement of material.

The writer's thanks are due to a large number of railway officials who have answered his many inquiries with great courtesy and patience. A personal mention of all who have favored him would savor more of ostentation than courtesy; but he is especially indebted to Mr. ALBERT FINK, of Louisville, Ky., for much information and kindly criticism; and to Mr. JACOB KEENE, the able and competent Roadmaster of the Eastern Division of the Erie Railway, for a large amount of information as to maintenance of way, collected with exceptional care, which the writer could obtain nowhere else. Only a small part of this information, unfortunately, was received in time to be included in this volume.

The word "ton" in this volume means 2,000 lbs.; unless otherwise explicitly stated. Great care has been taken to avoid all confusion in this respect.

A. M. W.

DANVILLE, Pa., March, 1877.

THE ECONOMIC THEORY
OF THE
LOCATION OF RAILWAYS.

Any two proposed lines will differ from each other in one or more of the following details of alignment:

1st. DISTANCE, or length of line;

2d. CURVATURE;

3d. RISE AND FALL, or elevations overcome by the engine on gradients not exceeding the ruling grade of the line;

4th. THE RATE OF THE MAXIMUM OR RULING GRADE, a totally distinct question from that of Rise and Fall, though often confused with it; and

5th. IN THE USE OF HIGH GRADES AND ASSISTANT ENGINES INSTEAD OF A LOWER UNIFORM RULING GRADE.

The same questions arise of course in the case of projected improvements in the alignment of roads in operation.

A correct and judicious solution of the problems arising from these differences in alignment is of the utmost importance to the financial future of every railway company, especially in the all-important subject of the adjustment of gradients; and although it is true that no rules of universal and exact application can be formulated, inasmuch as no item of future business or expenses can be exactly anticipated, yet nevertheless it is believed that by proceeding on correct principles an estimate can always be made which shall be a sufficient guide for location and should always be carefully followed in preference to mere "judgment" and guesswork. The latter are most uncertain and variable guides, even in the hands of the most experienced, and lead to a vast amount of useless expenditure and expensive economy.

To compare properly these different characteristics of alignment with each other, it is essential that the value or cost of each should be referred to some common standard. The TRAIN MILE is at once the most convenient and the most exact for this purpose. It is the most convenient, because it is more easily anticipated than any other item of future business, as tonnage, for example; and it is the most exact, because it is the most uniform measure of operating expenses—the cost of a train mile being very nearly the same, whether trains are habitually run full or empty or long or short; and it is thus the most suitable measure of any increase in running expense due to alignment.

Assuming, then, the standard of the train mile (which we shall do in the form of a more convenient equivalent, viz.: the number of daily trains each way over the line), every degree of curvature and every foot of distance or rise and fall entails a certain expense (variable or constant) upon every train which passes over the line, and it is proposed in this paper:

First, to demonstrate that these sums—and the relative percentages of the different items of expense which compose them —are more nearly constant than is generally supposed, under variable conditions of traffic and location ; and

Secondly, to express the amount of such expense in sums which, multiplied by the estimated cost of a train mile and the estimated number of daily trains, shall give a few sums, easily carried in the memory, which shall not only be equally convenient for the ordinary purpose of "equating," but shall also serve as an instantaneous guide as to *how much* any proposed change, great or small, is worth to the line in dollars and cents.

In order to have a sound foundation for a settlement of these problems, we must first investigate at some length the relations which the various items of the operating expenses bear to each other. This must necessarily be a dry and tedious mass of figures, but, it is hoped, will have interest sufficient to repay examination, independent of our present purpose.

THE LAWS OF RELATIONSHIP BETWEEN OPERATING EXPENSES.

If we examine the reports of almost any two widely-separated railways for any one year, it will be a chance if many of the items of cost per train mile do not vary from each other 200 or even 300 per cent.; and if we take the average of several contiguous roads in each case, or of several successive years, the result will be the same in a less degree. If, however, we make a careful separation by items in each year on each road, the resemblance will be much closer, inasmuch as the accounts of almost any two roads, which are apparently much the same, will differ so much in the combination of some of the minor items as to vitiate all comparisons.

But if, for the purpose of comparison, we determine only the aggregate cost of a train mile in dollars and cents, and then determine the *percentage* which each separate item of cost bears to that sum, the resemblance will be, in the main, singularly close, if the average of each road be taken for a series of years. And if, finally, we omit all taxes, station, terminal and general expenses, which are especially dependent on locality and character of business, and include only those items of expense which vary more or less with the alignment and train mileage, and which we may group together under the general term of "Line' or "Transportation" expenses proper, the similarity in the percentage of the various items will be so close as to indicate the existence of a relationship between those expenses more nearly independent than is commonly supposed of the volume of business and even of locality; at least amply sufficient to serve as a general basis for location estimates.

The results of such a comparison are summarized in the tables given below. The writer is not aware of such having been previously compiled, owing probably to the great labor involved. Nor, it may be added, would it have been attempted by the writer except that nearly every computation for this paper was read off at once from a "Diagram of Percentages" and hardly any numerical work performed except addition and subtraction.*

The operating expenses of a railway divide naturally, at least for our purpose, under the three great heads below:

1st. MAINTENANCE OF WAY AND WORKS, including all permanent structures except repair shops and engine and car sheds.

2d. TRAIN EXPENSES, including all expenses connected with the running, handling and maintenance of the rolling stock, but *not* including any station expenses.

3d. STATION, TERMINAL AND GENERAL EXPENSES AND TAXES, most of which vary more or less with the tonnage or volume of business, but all of which are independent of, or inappreciably affected by, any of the details of alignment; and therefore for our present purpose may be included together. Taxes at first sight appear to be affected by the alignment, inasmuch as they might increase with the length of the road; but taxes are based on *value* and not on cost; and as the shortest line between two points is necessarily the most valuable, taxes, if affected at all, should be inversely as the length, so far as the length is changed for engineering reasons. Station expenses also are the same for the same business, whatever changes in the alignment may be made, unless such change brings additional business; in which case the net profit on that business is an element additional to the purely engineering question.†

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* Even with this assistance, the preparation of the necessary tables, only a small portion of which are here reprinted, has been one of much labor, and the writer was led to add one road after another to the tables below only on account of the singular uniformity, as it appeared to him, of the percentages obtained. The diagram above mentioned reads to three digits, independently of the decimal point, except that the last digit may possibly be a unit in error; *e. g.*, the proper figures may be .0176 instead of .0177, or 14.5 instead of 14.4. The vanity of decimal precision is thus necessarily sacrificed, but the writer considers it more an obstruction than an assistance, both to the reader and to the value of the results. Of what possible value is a knowledge of the fact that fuel and water cost 11.6201 cents per train mile, as per reports of the Louisville & Nashville Railroad, instead of the even figures 11.6 cents?

Below is given a table (Table I.) showing the percentage which each of the various items of expense—divided up under the three great heads enumerated above—forms of the total aggregate expenditure on 13 representative roads of the United States. Also, at the foot of the table, similar percentages are given for the only three States which publish State summaries in any detail or of much value. All the State reports, however, as is well known, are very inaccurate in detail, and have only the advantage of a wide general average; the Massachusetts reports being the best and those of Ohio especially inaccurate and unsystematic, as respects uniformity in the individual reports.

The 13 roads given are as widely separated in location and exhibit as great a variety both in the character and in the volume of business as it was possible to compile from the reports accessible to the writer, and the shortest period averaged in any case is four years, except in the case of the Philadelphia & Reading Railroad, for which a subsequent table is given (Table VI.) covering a period of 24 years, which shows that the relative percentages have varied but little, but which it was impossible to include in Table I. for the entire period from lack of the requisite data, owing to the peculiar system of accounts in use on that road, as explained in the Notes to Tables I. and VI. The separate tables for each road, from which Table I. was condensed, are omitted as too voluminous, but in many cases they show wide fluctuations from year to year.

Table II. gives similar percentages to Table I., so far as the character of the State Reports enabled them to be compiled,

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† A neglect of the consideration that all items which vary with *tonnage* are not affected by the *alignment*, leads to a great over-estimate of the value of distance. Thus, Mr. Herman Haupt, in a paper on the value of distance on the Pennsylvania Railroad (*Van Nostrand's Engineering Magazine* Vol. IV., p. 593) includes such items as "station labor, $152,883," "teaming, $109,125," etc. It would be hard to say how the length of the track affects the cost of carting freight at the termini.

due to local or temporary causes. In order to determine, however, if the same law of uniformity will hold universally true, we will make some comparisons with a few English railways. The official returns of the Board of Trade afford a very meagre basis for this purpose, but accurate so far as it goes, and with the advantage that all returns are made upon precisely the same system.

Table IV. gives the average percentages of the various items, as returned to the Board of Trade, for three representative English railways, and also the aggregate of the English and of the Irish railways, for a period of five years in each case; and it will be observed that—excepting the Irish railways, on which we shall remark hereafter—there is a much more striking similarity in the various percentages than in the case of American railways. But it will also be observed that these percentages differ widely from those shown in Tables I. and II. for American roads.

This difference, however, is only apparent, and is owing to a singular anomaly in the English system of keeping railway accounts—in use also on the Philadelphia & Reading and a few other American roads—termed the "Renewal Fund," which is formed by deducting a certain amount per ton or per passenger transported directly from the receipts for the renewal of iron and rolling stock, which is not charged in with other receipts and expenses. No trace of this fund appears in the English official returns, either in the reported receipts or "Total Working Expenses," nor does any means exist, so far as the writer can ascertain, of determining exactly what is ordinarily understood in the United States as the "Total Working Expenses" of any year, except in the private books of the several companies. Inasmuch as the main expenditures from that fund are on maintenance of way, and few Americans are aware of this system, the English railways and the English system of building railways enjoy a cheap reputation in this country for

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REMARK ON TABLE II.—*The average number of trains daily* is computed above, including the entire length of branches, without "equating" the length of branches as in Table I. The extraordinary excess of the freight business of Pennsylvania, over New York and other States, is as the returned mileage indicates.

Maintenance of Engines and Cars.—In Michigan this item included fuel in most reports and excluded car repairs in some others. The percentage above is accordingly about 4 per cent less than is indicated by the face of the returns. In Connecticut, the cost of fuel (13 per cent.) was deducted from the percentage given by the face of the returns.

Little value attaches to any of the results shown in this table, except as a check, as the averages are for so short a period, and all the reports are more or less inaccurate and unsystematic.

economy in that item and low cost per train mile. As a matter of fact, the English railways have no considerable advantage in these respects, if we may trust the indications of the following confessedly inexact process.

It will be observed that the percentages of the Philadelphia & Reading Railroad, as given in Table IV., with renewal expenditures omitted, agree quite closely with the percentages of the English Railways; as do also the percentages of the same road with American railways, in Tables I. and III., when the renewal expenditures are included. A more exact method of comparison, however, so far as it affects maintenance of way, is afforded by an elaborate paper by Mr. R. Price Williams, "On the Maintenance and Renewal of Permanent Way," (Trans. Inst. Civ. Engrs., 1866). Mr. Williams having had access to the accounts of eight leading English Railways (viz., the London & Northwestern, the Northeastern, the Midland, the London & Southwestern, the Great Northern, the Lancashire & Yorkshire, the Southeastern, the London, Brighton & South Coast, and the Manchester, Sheffield & Lancashire), gives a table for these roads extending over a period of five years (1860-65), showing the expenditures per mile, both from operating expenses and from the "Renewal Fund" on what is ordinarily understood in the United States as "Maintenance of Way." From this we may determine that expenditures from the renewal fund vary from 74 per cent. on the Lancashire & Yorkshire Railway to 27.3 per cent. on the Manchester, Sheffield & Lancashire of the official return to the Board of Trade as the cost of "Maintenance of Way and Works;" the average of the eight roads being 46.5 per cent., as against 34.9 per cent on the Philadelphia & Reading Railroad. Assuming these roads to be fairly representative of the entire English railway system—and Mr. Williams states them to be so—the total cost of maintenance of way on the railways given in Table IV. would be increased to from 25 to 28 per cent. of the total expenses, including expenditures from the renewal fund in both cases. The exact amount cannot be determined for lack of information as to the expenditures from the renewal fund on the maintenance of

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REMARK ON TABLE IV.—*Average Number of Daily Trains.*—This column was computed, including the full length of branches, instead of "equating" their length in proportion to business transacted, as in Table I. On the other hand, the returns presumably include construction as well as revenue trains, which is not the case in Table I.

The cost per train mile was converted into Federal money at 2 cents per penny.

rolling stock. These expenditures, in the case of the few American roads maintaining a renewal fund, are comparatively small, but the percentages would indicate that they are somewhat larger in England. The renewal fund apparently amounts to from 10 to 15 per cent., thus bringing the *true* cost of a train mile up to 80 to 90 cents, gold.

We thus find reason to believe that the various percentages of cost on English railways, and even the aggregate cost of a train mile, are closely approximate to those ruling in the United States, despite the great dissimilarity on the face of the returns. The Irish railways, however, form an apparent anomaly in Table IV.; the cost of maintenance of way amounting to 26.6 per cent. of the total returned expenses, instead of only 18.3 per cent. in the case of the English railways; and it will perhaps be at once concluded that this is due to the striking difference in the volume of business, which is also shown in Table IV. In the absence of information as to the comparative amount of the renewal fund on Irish railways, the writer is unable to dispute this conclusion, but can only express his belief, based upon the general identity of the results already obtained, that the Irish railway accounts are kept on a different system, and that the renewal fund is either non-existent or very small. This conclusion, which is purely *a priori*, may be easily contradicted, if incorrect, by those familiar with the facts. If it be not so, it is quite possible that, from conservatism and fancied necessity, the whole system of Irish railways is maintained in English style for an Irish business.

DIVISION OF THE EXPENSES FOR MAINTENANCE OF WAY.

An analysis of the relative cost of the different items of expense for maintenance of way is evidently necessary for our present purpose, in order to determine how great a proportion of the aggregate expense is affected by the various changes in alignment. Few roads, however, and no State reports, attempt to divide up this expense minutely under heads similar to those shown in Table V. below; but the Pennsylvania, the Philadelphia & Reading, the Louisville & Nashville and others do so in

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Remark on Table V.—In compiling the table, it was found impossible to determine the cost of sidings separately, except on the Philadelphia & Reading Railroad. It was also impossible to separate the cost of maintenance of shops from other buildings entirely. Hence, the column of "Switches and Sidings," in fixing the last line of percentages in the table, was increased from the columns of "Rails," "Ties," and "Track Surfacing," by a percentage of about 1-10 in each case; and the column of "Earthwork, Ballast, etc." (which includes culverts and ditches), was increased from the column of "Buildings."

TABLE V.

Showing the Percentage of the Various Items of the Cost of Maintenance of Way, for a series of years, on different Railways and from State Reports.

NAME OF ROAD.	No. of years averaged.	Dates (inclusive).	Statistics for last year.					Percentages.										
			Length.		Av. No. of daily trains.		Cost of Maintenance of Way per train mile.	Renewal of rails.	Track and Roadbed.					Structures.				Grand total.
			Main Line.	Branches.	Passenger.	Freight.			Ties.	Earthwork, Ballast, etc.	Track Surfacing.	Switches, frogs and sidings.	Total.	Bridges and Bridge Masonry.	Buildings.	Wharves and Machinery.	Total.	
Pennsylvania	2 years.	1867–71	358	426	11.	32.8	$0.25	30.1	9.8	15.7	28.8	2.6	56.9	....	....	....	13.0	100.
Philadelphia & Reading	3 "	1868–70–73	95	332	6.	44.	0.26	23.8	11.5	5.4	28.8	8.	53.7	6.2	7.6	8.7	22.5	100.
Louisville & Nashville	3 "	1871–73	185	207	3.1	6.5	0.41	39.3	13.4	8.4	18.8	4.1	44.7	8.2	7.8	....	16.	100.
Illinois Central	8 "	1865–73	456	250	3.	7.	0.275	25.	12.	21.	22.	7.	62.	12.	1.	....	13.	100.
New York State Railroads	5 "	1870–74	6,574	1,977	3.5	8.4	0.28	30.5	....	....	....	....	54.5	7.	8.	....	15.	100.
Massachusetts State Railroads	5 "	1871–75	2,459	......	7.4	6.7	0.30	24.5	....	....	....	....	54.1	7.3	14.1	....	21.4	100.
Averages								28.9	11.7	12.6	24.6	5.4	54.3	8.5	8.3	....	16.8	100.
Corresponding percentage which each item forms of the *aggregate cost of a train mile*, allowing the aggregate cost of Maintenance of Way to be 27 per cent. of said cost, as shown in Table I.								7.8	3.2	3.4	6.6	1.5	14.7	2.3	2.2	....	4.5	27.
Do. do. as adopted for the purposes of this paper								7.	3.	4.	6.	3.	16.	2.5	1.5	....	4.	27.

rolling stock. These expenditures, in the case of the few American roads maintaining a renewal fund, are comparatively small, but the percentages would indicate that they are somewhat larger in England. The renewal fund apparently amounts to from 10 to 15 per cent., thus bringing the *true* cost of a train mile up to 80 to 90 cents, gold.

We thus find reason to believe that the various percentages of cost on English railways, and even the aggregate cost of a train mile, are closely approximate to those ruling in the United States, despite the great dissimilarity on the face of the returns. The Irish railways, however, form an apparent anomaly in Table IV.; the cost of maintenance of way amounting to 26.6 per cent. of the total returned expenses, instead of only 18.3 per cent. in the case of the English railways; and it will perhaps be at once concluded that this is due to the striking difference in the volume of business, which is also shown in Table IV. In the absence of information as to the comparative amount of the renewal fund on Irish railways, the writer is unable to dispute this conclusion, but can only express his belief, based upon the general identity of the results already obtained, that the Irish railway accounts are kept on a different system, and that the renewal fund is either non-existent or very small. This conclusion, which is purely *a priori*, may be easily contradicted, if incorrect, by those familiar with the facts. If it be not so, it is quite possible that, from conservatism and fancied necessity, the whole system of Irish railways is maintained in English style for an Irish business.

DIVISION OF THE EXPENSES FOR MAINTENANCE OF WAY.

An analysis of the relative cost of the different items of expense for maintenance of way is evidently necessary for our present purpose, in order to determine how great a proportion of the aggregate expense is affected by the various changes in alignment. Few roads, however, and no State reports, attempt to divide up this expense minutely under heads similar to those shown in Table V. below; but the Pennsylvania, the Philadelphia & Reading, the Louisville & Nashville and others do so in

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Remark on Table V.—In compiling the table, it was found impossible to determine the cost of sidings separately, except on the Philadelphia & Reading Railroad. It was also impossible to separate the cost of maintenance of shops from other buildings entirely. Hence, the column of "Switches and Sidings," in fixing the last line of percentages in the table, was increased from the columns of "Rails," "Ties," and "Track Surfacing," by a percentage of about 1-10 in each case; and the column of "Earthwork, Ballast, etc." (which includes culverts and ditches), was increased from the column of "Buildings."

into that item are not affected by minor changes of alignment; and, moreover, Table I. shows the general rule to be that such expenses are very uniformly about 30 per cent. of the aggregate, taking the average of years, except in the case of such exceptional roads as the Baltimore & Ohio, the Union Pacific, and for example, the Syracuse, Binghamton & New York, on which the general and station expenses amount to but 20.4 per cent., including taxes. Even variations so great as these, however, would cause little error in the application of the formulæ to be given.

But as respects the items which enter into the "Line" or "Transportation" expenses proper, this objection would have more weight; and more especially, if the relative cost of maintenance of way is continually changing with the volume of business, as is very frequently imagined and assumed. The following facts seem to indicate, however, that, be the cause what it may, no such changes are to be observed, either in the history of individual roads or in comparison of different roads with each other; unless in some exceptional instances or in comparisons of main and branch lines, where, it may be, the contagion of example leads to keeping up branch lines in better relative condition than the circumstances require or justify, and on which at the same time the running and general expenses are very generally less than if independently operated.

An examination of Table I. (and more especially of Table III., which is an abstract from Table I. to show the exact relationship of "Maintenance of Way" and "Train Expenses") fails to show any considerable difference in the ratio of expenses due to volume of business. Among the lowest percentages for the cost of maintenance of way is the Cheshire Railroad, and among the highest the Lake Shore, the Pennsylvania and the Baltimore & Ohio. The State averages also are practically identical with those for the great roads given above them. Several roads of comparatively small business run, indeed, somewhat above the average, but this is largely due in each case to obviously temporary causes; thus, the Union Pacific Railroad was engaged in erecting snow sheds and filling trestles during the period covered by the table. On the Baltimore & Ohio, the cost of maintenance of way *increased* about 1 per cent. during the 20 years from 1855 to 1875; the returned cost for "Repairs of Way" having been, for the five years 1871–75, 17.4 cents per train mile, and for the five years 1851–55, 13.2 cents per train mile. Similarly, the English railway returns, in Table IV., show a striking identity in the percentage of maintenance of way with varying volume of business; these returns, it must be remembered, do *not* include the cost of renewing track, which is admitted to vary very nearly with running expenses, but only of repairs and maintenance of works.

As a further fact, the following table (Table VI.) summarizes the operation of the Philadelphia & Reading Railroad for a period of 24 years. It is given in full, although only a portion of it is required for our present purpose, as an interesting resume of the history of a leading railroad. It will be observed that the relative cost of maintenance of way has slightly but steadily *increased* for a period of 24 years (in almost exact proportion to the weight of engines), while at the same time the relative cost of the direct running expenses has somewhat decreased; the volume of business, measured by the standard of the train mile, having more than doubled during the period included; and as measured by tons transported, increased five-fold. And it must be remembered that this table, as in the case with the English railways, in Table IV., does *not* include the cost of renewing rails, but only the care and maintenance of road-bed and track.

As evidence that the experience of the Philadelphia & Reading Railroad is not exceptional, the following table shows the relation of the cost of maintenance of way to the cost of locomotive charges on the Great Northern Railway of England, for a period of 23 years. The first and third columns are taken from the paper before referred to by Mr. R. Price Williams, "On the Maintenance and Renewal of Permanent Way," (Trans. Inst. Civ. Engrs., 1866); the remainder of the table was added by the writer.

If the final column of Table VII. be examined, it will be observed that, barring a slight irregularity at the beginning of the table, when the works were new and entailed little expense (the railway was opened for business in September, 1850, and new *English* railways are in very perfect condition), the cost of maintenance of way bears a singularly uniform but slightly increasing ratio to the cost of locomotive power for a period of about 20 years, during which period the volume of business, measured by the number of daily trains, was considerably more than doubled. We thus have a very close parallel to the experience of the Philadelphia & Reading Railroad.

Mr. Williams was evidently struck by the fact that no evidence of relative decrease in the cost of maintenance of way

TABLE VII.

Showing the Ratio of the Cost of Maintenance of Way (Renewals not inincluded), to Locomotive Charges on the Great Northern Railway of England, for a period of 23 years:

YEAR.	Percentage of locomotive charges		Percentage of maintenance of way		Percentage on locomotive charges of maintenance of way.
	On gross traffic receipts.	On gross traffic expenses.	On gross traffic receipts.	On gross traffic expenses.	
1851	17.19	....	4.09	....	24.
1852	14.24	....	4.80	....	34.
1853	13.87	....	5.61	....	41.
1854	15.40	....	8.21	....	54.
1855	16.50	....	7.76	....	48.
Average	....	....	....	....	40.2
1856	15.40	25.2	8.21	13.4	53.
1857	15.11	....	9.73	....	64.
1858	16.01	....	9.32	....	58.
1859	14.83	....	9.59	....	64.
1860	15.30	28.7	9.86	18.5	64.
Average	....	....	....	....	60.6
1861	15.21	....	9.27	....	61.
1862	15.13	....	9.10	....	60.
1863	14.58	....	10.23	....	70.
1864	15.28	....	10.42	....	67.
1865	16.94	....	9.99	....	58.
Average	....	....	....	....	63.2
1869	....	27.2	....	18.2	67.
1870	....	26.5	....	18.6	70.
1871	....	26.4	....	18.9	71.
1872	....	27.8	....	18.7	8.
1873	....	30.4	....	19.	2.
Average	....	....	....	....	67.6
General average	....	....	....	....	57.9

REMARK ON TABLE VII.—The writer did not have the data accessible by which to continue the table for the later years in the same form as for the earlier ones, but percentages on gross expenses evidently serve the same purpose as percentages on gross receipts for determining the ratios in the last column.

as business increases was apparent in this table and others of his paper, for he makes the following comments thereon:

"It must be confessed that the condition of the permanent way, so far as regards its durability, has in no way kept pace

TABLE VIII. A.

Showing the Cost of Maintenance of Way per mile of road and the cost per train mile for different items thereof, on Massachusetts Railroads of varying business.

YEAR.	Eight Boston Roads				Other Mass. Roads.			
	Aggregate cost of maint. of way per mile of road.	Cost per train mile.			Aggregate cost of maint. of way per mile of road.	Cost per train mile.		
		Road repairs.	Renewal of rails	Total cost per train mile.		Road repairs.	Renewal of rails	Total cost per train mile.
1872............	$3,380	.167	.089	1.32	$2,300	.176	.094	1.30
1873............	3,682	.200	.073	1.284	2,155	.163	.099	1.342
1874............	2,757	.163	.087	1.198	2,505	.137	.060	1.253
1875............	2,489	.157	.060	1.150	2,293	.144	.044	1.220
Average	$3,077	.1716	.0773	1.238	$2,313	.1550	.0742	1.279

	8 Boston Roads.	Other roads
Percentage on Total Expenditures of Road Repairs	13.9	12.1
Percentage on Total Expenditures of Renewal of Rails.............	6.2	5.7
Ratio of Cost of Road Repairs to Wear of Rails..................................	2.22	2.10

REMARK ON TABLE VIII.—In the last two years above the "other Massachusetts roads" given in the reports include only a few representative roads doing a larger average business than the roads omitted. Consequently, the contrast in the volume of business between the "Boston roads" and the "other roads" is less striking than in the first two years or than it would otherwise have been, although the table clearly indicates that the result would have been the same. For the year 1872 (Report of 1873) the Boston roads are not separated from the others in the reports; otherwise the statistics are exactly as given in the State reports.

TABLE VIII. B.

Showing comparative Statistics of the Cost of Maintenance of Way on all the Railways of the State of New York and on the 4 railways therein having the greatest volume of business. For the year 1873 and for freight business only.

	Freight earnings.		Expenses, per freight train mile.	Cost of maint. of way per train mile.		Perc'ntage of total fr't expenses.	
	Per mile of road.	Per train mile.		Roadbed & track only (excepting iron).	All expenses (including taxes).	Roadbed & track only (excepting iron).	All expenses for maint. of way.
Average of all the railways of the State	$7,620	$1 50	$1.054	15.3 cts.	26.8 cts.	14.5	25.4
Average of 4 leading railways, viz.:							
N.Y. Cen. & H. R......... Erie. .... Lake Shore & Mich. So... Boston & Albany	$26,642	$1 69	$1.181	15.7 cts.	30.0 cts.	13.4	25.4

Remark.—These statistics are for freight only, as being easier to compile; but the expenses as alloted to "passenger and freight business" in the New York State Reports differ but little either in the aggregate amount per train mile or in the percentage chargeable to the various items of expense.

The four great roads above vary but little from each other in volume of business (viz., from $23,000 to $30,000 freight earnings per mile), and the average of $26,642 per mile exceeds by nearly $20,000 per mile that of any other railways of the State. As their aggregate receipts amount to four-fifths of those of all the railways of the State (viz., $51,800,000 out of $65,100,000), and their length to only three-eighths (viz., 3,382 miles out of 8,552), the contrast in the above table would have been much more striking had the business of the four great roads been excluded from the general aggregate. For example, the freight earnings per mile of road for all the other railways of the State would have been only $2,380 per mile, instead of $7,620; yet it is obvious that the comparison in the latter part of the table would have been inappreciably affected.

Other facts of a similar nature might be adduced, did not space forbid; noticeably the admirable colored diagrams which accompany Mr. Williams' paper and at once illustrate to the eye the following facts :

1st. That all the main items of expense continue in an approximately constant ratio to each other as business increases.

2d. That *none* of the items of expense, not even locomotive charges, increase quite in proportion to train mileage, and, in a very marked degree, increase less rapidly than the tonnage.

Facts from so many independent sources would seem to make evident that either the cost of track maintenance proper must increase considerably *faster* than the train mileage, which is unreasonable; or that the remaining expenses for maintenance of way, which are apparently independent of train mileage, must increase nearly in proportion. At least it cannot lead us into great error to assume this to be so, for the purposes of solving problems of location, however it may be for the determination of freight rates and similar questions which arise in the operation of railways, and require in many respects a different classification of expenses. It would lead us too far to attempt any explanation of this singular constancy of ratio, but all the facts seem to indicate that a larger increase than is commonly assumed in the expenditure on such items as ditches, ties, bridges, earthwork and masonry, is absolutely essential for the exigencies of a large business, although it is not advisable for a smaller one ; or at least that experience proves it to be *economy*, whether it be absolutely essential or not, to expend an amount increasing in equal ratio with the cost of running trains on the perfection of the road-bed and track. A further reason is, that even the direct train expenses do not increase nearly as fast as the volume of business, even if measured by the standard of the train mile. Comparisons of main line and branches are hardly a fair test of this question, as before stated, because the general operating expenses are almost uniformly less than if the branch were independently operated, and the expenditure on maintenance of way almost as uniformly greater.

SUMMING UP THE PRECEDING CONCLUSIONS,

we may assume, on the authority of Tables I. to V., that the following percentages represent very closely the *relative* cost of the various items of expense which enter into the operation of railways, taking the average of years; and that this relative cost or percentage is much less liable to fluctuation than the actual expenditure in dollars and cents;

Classification of Operating Expenses.

Train Expenses	43 p. c.	Engines	21 p. c.	Fuel	10 p. c.
				Oil, Waste, etc.	2 "
				Repairs	9 "
		Cars	10 "	Repairs, inspection, etc	10 "
		Train Hands	12 "	Eng'eman and Firemen	6 "
				Conductor and brakemen	6 "
Maint'ce of Way	27 "	Track	13 "	Renewal of Rails	7 "
				Adjust'g track, etc	6 "
		Roadbed	7 "	Ren'al of Ties	3 "
				Earth'k, Ballast, etc	4 "
		Yards and Structures	7 "	Switches, frogs and Sidings	3 "
				Bridges and Br. Masenry	2.5 "
				Station and other Build'gs	1.5 "
Total "Line" or "Transportation" Expenses	70 "		70 "		70 "
Station, terminal and general expenses and taxes	30 "		30 "		30 "
Total Operating Expenses	100 "		100 "		100 "

These percentages we have seen to be most liable to variation in the items of "Station and General Expenses," but that the items of line or transportation expenses in such cases will still preserve, as a rule, a nearly constant ratio to each other, as above; the item of fuel being the most liable to irregular fluctuations.

If we assume, for even figures, the low average of $1 as the cost of a train mile (*i. e.*, 70 cents per train mile transportation expenses proper), these percentages will also represent the cost of the renewal items, per train mile, in cents; and inasmuch as we have seen them to apply as percentages, within a small margin of error, to 13 representative roads and four State averages, we may use formulæ or values so obtained, without serious error, for any other cost per train mile, assumed or actual, by simply multiplying by such cost, without necessary consideration in each case of each separate item.

We have also seen that these percentages are but little affected by the volume of business, in the items with which we are most concerned, and are hence equally applicable to roads of either a large or a small business; at least sufficiently so for the solution of the various problems of location, which we will now proceed to consider.

REDUCTION OF LENGTH.

We may premise that the increase in operating expenses caused by the adoption of a longer line is by no means a constant quantity per unit of length, although often assumed to be. In the first place, a longer line may be adopted either for the purely engineering purpose of securing lower grades or lighter work; or, secondly, for the commercial purpose of thereby securing a larger way business. In the latter case, we have, in addition to the same purely engineering questions as before, the further question of the capitalized value to the line of such additional way business. It is with the former case only that we are directly concerned, but even in that case the value of a mile saved is by no means the same whether the total saving be one mile or twenty. The number of yearly trips of rolling stock, number of stations and sidings, etc., and the considerable class of expenditures which vary with those items, remain nearly constant under the small changes of distance, which most frequently occur, and are not perceptibly affected until the change of length amounts to a considerable percentage. How much the expenses are increased by such relatively small changes of length we will first endeavor to determine, by examining separately the various items of expense; premising that this must be done in some detail if the conclusions are to possess any value, and that it is better to err, if at all, by underestimating the increased expense due to unfavorable alignment, in order that all extra outlay on construction may be fully justified.

Fuel and Oil.—A very considerable percentage of the consumption of fuel is a constant wastage, nearly independent of the exact distance run. The cost of kindling fires only averages about 10 per cent. of the cost of fuel on the Philadelphia & Reading Railroad as shown in Table IX below. Mr. Russell Sage, Jr., in an article in *Van Nostrand's Engineering Maga-*

zine for 1873 says: "I am assured that a dead engine cannot be fired up for less than $2.00." This would amount to nearly 20 per cent. of an average cost for fuel, and is probably an excessive estimate; but information from various sources which the writer has been able to secure indicates that this expense averages about 10 per cent. of the cost of fuel. The consumption due to stopping and starting and to standing idle in yards and on side tracks is also a heavy item, and may be considered as nearly independent of distance in the case of two *nearly* equal lines operating under the same conditions between the same termini. The direct loss of power in stopping a train running at a speed of 25 miles an hour would be sufficient to run the train over a mile; and, as to the wastage while standing idle, the writer is informed that a saving of 10 or 15 per cent. has been observed on the New York Central Railroad since freight trains are partly relieved from this expense by independent freight tracks. These two sources of waste combined may be estimated at 20 per cent., or, including 10 per cent.

TABLE IX.

Showing the Relative Cost of Wood for Kindling on the Philadelphia & Reading Railroad for a Series of Years.

YEAR.	Percentage of the cost of kindling wood to remaining cost of fuel.			Prices of fuel.		Average consumption of Wood for kindling.
	Passenger trains.	Freight trains.	Coal trains.	Wood per cord.	Coal per ton.	
1867....	14.2	10.	5.1	$5 79	$3 15	Passenger trains, .13 c'd.
1869....	8.8	6.4	3.6	5 50	3 80	Freight " .15 "
1873....	9.7	6.2	4 1	5 94	3 25	Coal " .22 "
Average	10.9	7.5	4.3	$5 74	$3 40	

Remarks.—The above does not include the cost of any coal used in kindling. The consumption of wood seems very small; Mr. Trautwine (Engineers' Pocket Book, p. 411) gives ⅓ cord as the average consumption.

When this road was using wood fuel entirely, passenger trains used 2.7 cords per 100 miles, or about 2½ cords per daily run of 93 miles. Allowing ¼ cord for getting up steam would amount to exactly 10 per cent.

for firing up, we have a total of 30 per cent. as a wastage independent of a slight change more or less in the length of the run. At least one-half of the cost of oil, waste and water is similarly independent of distance.

Repairs of Engines and Cars.—Such portion of this expense as is due to making up trains, stopping and starting, loading and unloading, and to the effect of time and age is nearly independent of minor variations in length. The extent of the deterioration from these causes, in distinction from the regular running wear is purely a matter of opinion; the writer has heard it variously estimated at from 1-5 to ½. Thirty per cent. would seem a moderate estimate, or, of the total cost of 19 per cent. for these items we may say that 14 per cent. only is due to the regular running wear while in motion.

Train Wages.—This expense is practically independent of very small variations of length, and when the train hands are paid by the day or month, is even independent of changes of several miles. On most railways, however, the engine crew is paid by the mile, and, on an increasing number, all train hands are so paid without distinction. For changes of length of less than half a mile it may properly be omitted altogether, and for greater changes it may be allowed for, if necessary, by increasing the estimate for small distances, by a proper percentage, as will be done below.

Maintenance of Way.—The cost of yards and structures is practically independent of small variations in length, since the number of stations, important bridges, etc., will be probably the same on any two alternate lines, or will even be less on the longer line, as a rule, for obvious engineering reasons. The remainder of the cost of maintenance of way, however, including all track and road expenses, may be considered as varying directly as the distance.

Station Expenses and Taxes.—Since taxes are based upon *value*, and a short line is worth more than a long one between the same points, taxes may be said to be independent of, if not inversely as, the length. Station and general expenses also are practically independent of variations in length, unless the *volume* of business is also affected, which is outside of the purely engineering question.

Summing up these items, we have, as the cost per train-mile of minor changes of distance:

	Total cost of item at $1 per train-mile.	Proportion of same increasing with distance.	Cost of running one additional mile.
Fuel........................	10 cts.	70 per ct.	7 cts.
Oil, waste and water	2 "	50 "	1 "
Repairs of engines and cars....	19 "	70 "	14 "
Train wages	12 "	unaffected by small changes.	......
Maintenance of way	27 "	all but y'ds and structures.	20 "
Station and general expenses..	30 "	unaffected.	......
Total	$1.00	42 per ct.	42 "

In other words, the cost per mile of *additional* distance is only about 42 per cent. of the average total cost of a train-mile, in the case of such minor changes of length as do not appreciably increase the expense for train wages. At what distance such increase begins is a question for settlement in each case. The percentage by which the above estimate must be increased, for more considerable changes of distance, we shall consider below.

Expressing the above cost per train mile in terms of the yearly cost per daily train: In a year there are 313 week days. Making some allowance for Sunday and incidental business, we may say that each daily train will represent on an average 325 round trips yearly over the line, hence the *cost per year per daily train of one additional mile* will be—

$\$0.42 \times 325 \times 2 = \$273$ (*i. e.*, 273 times the average cost of a train mile).

From this we have, as the *cost per year of one additional foot*,

$\frac{\$273.00}{5,280} = \$0.0517$ (*i. e.*, about 5 per cent. of the average cost of a train mile).

These sums, divided by the rate of interest on the capital (.06, .07, &c.), give the capitalized value of saving one foot and one mile of distance which is given in the first column of the table (Table A) below.

In the case of projected improvements in the alignment of railways already in operation, we may more conveniently estimate the value of distance on the basis of the average annual expenditure per mile of road, either in the aggregate or, more correctly, that for the affected items only. For this purpose, we may express the cost of operating one additional mile of distance in any one of the following ways: the relative accuracy of each being as it includes all those items which are affected and excludes all those unaffected. An estimate on the basis of the *total* expenditures per mile is thus the most inaccurate of all.

The yearly cost of operating one mile more or less is

42-100, or 0.42 times the average yearly TOTAL EXPENSES per mile.

42-70, or 0.6 times the average yearly "transportation" or "line" expenses per mile.

42-23, or 1.826 times the average yearly maintenance of roadbed and track expenses per mile.

42-31, or 1.355 times the average yearly cost of fuel, oil and repairs of engines and cars per mile.

42-37, or 1.135 times the average yearly cost of fuel, oil, repairs of engines and cars, and engine wages per mile.

The amounts, or percentages, last given above, multiplied by the yearly expenditure per mile for the item opposite to it, give the total yearly cost per mile of operating additional distance, and divided by the rate of interest on capital, give the capitalized value of saving distance. We thus obtain (dividing by 5,280 for the value of one foot) the last four columns of Table A.

THE COMPARATIVE VALUE OF GREAT AND SMALL REDUCTIONS OF DISTANCES.

As we have before stated, the value per mile of saving distance is not a constant quantity. When the saving of distance is more considerable than we have been previously considering, or at some point varying from 1 to 5 or 10 miles, according to the practice of the road in respect to the standard for train wages, the cost of that item will be affected in proportion to distance. For such considerable changes, also, the cost of switches and sidings and the constant wastage of fuel from standing idle on side tracks may be considered as somewhat increased. Allowing one-third of the cost of switches and sidings (or 1 per cent. of the total expenses) as varying with such increase; and also one-third of that portion of the cost of fuel which we have previously regarded as constant, we have as the increased value per mile of a considerable saving of distance over a minor one:

Train wages	12 cents per train mile
Fuel	1 " " " "
Switches and sidings	1 " " " "
Total	14 cents per train mile

The value of small distances saved we found to be 42 cents per train mile. or 42 per cent. Hence we may say that a saving of several miles is worth $\frac{14}{42}$ or 33 per cent. more per mile than a minor one, and the values given by Table A should be increased by that percentage. If a portion only of the cost of train wages is considered as affected, the percentage should of course be proportionally reduced.

For very large and considerable differences of length, amounting to 15 or 30 miles in 100, the value of saving distance may properly be still further increased, up to the figures at which *all* saving of distance without distinction is very commonly estimated, to the serious loss of many railway companies from unjustifiable expenditure, as the writer feels compelled to believe. The conditions of the question are then totally changed. *The number of daily or yearly trips* which the rolling stock and employes can make over the line will then be increased nearly in proportion to the reduction of distance and their number can be correspondingly diminished, *whereas they otherwise cannot.* Hence all train expenses and the entire cost of maintenance of way may be considered as varying directly with the length. Station, terminal and general expenses, however, would be very little affected, the volume and character of business being always supposed to be the same.

The total amount of the transportation expenses, or the sum of train expenses and maintenance of way, we have estimated at 70 per cent., or 70 cents per train mile*, or 28 cents greater than our estimate for minor differences of length, (42 cents), used in constructing Table A; and strictly in accordance therewith the values given in that Table should be increased by $\frac{28}{42,}$ or 67 per cent. But as all experience seems to indicate that even direct train expenses cannot be reduced *in practice* in direct proportion to distance, although it may appear that they should be in theory, even if the saving were

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* It is usually taken, in round numbers, at ⅔. *E. g.*, Vose's "Manual for Railroad Engineers," quotation from Mr. Trautwine, foot note to p. 46.

TABLE A.

SHOWING THE CAPITALIZED VALUE PER MILE AND PER FOOT OF SAVING SHORT DISTANCES, NOT AFFECTING THE COST OF TRAIN WAGES; ASSUMING A TOTAL COST PER TRAIN MILE OF $1.00.

RATE OF INTEREST ON CAPITAL.	PROJECT'D LINES.		RAILWAYS IN OPERATION.			
	For each estimated daily train (round trip) over the line.	For each estimated $1,000 of yearly expenditure per mile.	Multiply the average annual expenditures per mile for any one of the following items, by the number given below it, opposite the proper rate of interest.			
			(1)	(2)	(3)	(4)
			All transportat'n" or "line" expenses.	Repairs rolli'g stock and fuel, oil, &c.	Maintenance of way (except bridges and buildings).	Motive power (including wages) and repairs cars.
			VALUE OF ONE MILE.			
5 per cent......	$5,460	$8,400	12.	27.1	36.5	22.7
6 "	4,550	7,000	10.	22.6	30.4	18.9
7 "	3,900	6,000	8.6	19.4	26.1	16.2
8 "	3,410	5,250	7.5	17.	22.8	14.2
10 "	2,730	4,200	6.	13.5	18.3	11.3
YEARLY COST of one additional mile	$273	$420	0.6	1.355	1.826	1.135
			VALUE OF ONE FOOT.			
5 per cent......	$1.03	$1.60	.0023	.0051	.0069	.0043
6 "	0.86	1.33	.0019	.0043	.0058	.0036
7 "	0.74	1.14	.0016	.0037	.0050	.0031
8 "	0.65	1.00	.0014	.0032	.0043	.0027
10 "	0.52	0.80	.0011	.0026	.0035	.0022
YEARLY COST of one additional mile..........	$0.0517	$0.08	.000114	.000257	.000346	.000215

REMARKS.—If the cost per daily train be higher or lower than $1.00, the value PER DAILY TRAIN given above must be multiplied by that assumed cost.

For any saving great enough to decrease the cost of all train wages per trip, the values given above must be increased by a maximum of 33 per cent., and for very considerable distances sufficient to increase the number of daily or yearly trips over the line by a maximum of about 50 per cent.

as much as one-half, 50 per cent. instead of 67 is probably an ample if not excessive estimate.

The limits of distance which should fix these several values in either direction are of course very indeterminate, and will vary in each particular case; but the values of Table A may be regarded as nearly constant for the minor changes which are of most frequent occurrence in location, and 50 per cent. increase therefrom as a nearly constant maximum for the most considerable changes.

THE EFFECT OF WAY BUSINESS ON THE VALUE OF SAVING DISTANCE.

The receipts from through business and a portion of the way business are usually (but not always) fixed by competition, and hence quite independent of the exact distance hauled; but a certain large proportion of the receipts of all railway companies is from way business, and in many instances the receipts from a part or all of this business are, either by law or custom, fixed by the mile. This fact, if there be any proportion, however small, of such business, is an element entitled to consideration in determining the value of a proposed saving of distance. So far as it is entitled to weight it evidently operates to reduce the value of any such saving.

The following table (Table X.) shows the average paying load per train in several different states and on separate railways; and also, where the statistics could be ascertained, the percentage which local or way business forms of the aggregate.

Judging by the indications of Table X. it is a low estimate to assume 60 passengers or tons of freight as the average load of a train; and it is also a low estimate to assume that the receipts from that portion of the way business on which the receipts are limited solely by the mile, or the will of the company, is at least one-half of the aggregate and generally more. Assuming an average rate on such business of 3 cents per mile, this gives us at least 90 cents per mile per train as the average receipts from such business.

Considering now the effect of these facts on the value of gaining distance, we have already seen that the cost of running an extra mile averages from 42 to 56 cents, if we assume an average cost per train mile of $1.00, or from 42 to 56 per cent., whatever the average cost per train mile. This includes *all* expenses for running such distance, and any additional receipts therefrom must be credited against it in full. Accordingly we see that where way rates

TABLE X.

Showing the average paying load of trains and the average proportion of local business for several States and individual Railways.

Name of State or Railway.	Date of Report.	Average Load of Trains.		Per cent. of local business to aggregate business.
		Passengers.	Tons Freight.	
New York..............	1874	60.	102.3	
Massachusetts............	1876	69.	65.	42. (fr't)
"	1874	75.	65.	71. (pass'r)
Connecticut..............	1874	61.	55.	
Ohio....................	1873–4	42.	68.	71. (freight)
Michigan.................	1873	49.	...	
L. S. & Mich. So...........	1874	72.5	147.5	89. (freight)
N. Y. Central............	1874	79.	139.	
Erie....................	1874	49.5	105.	
Pennsylvania...........	1873	58.	110.	65. (freight)
Louisville & Nashville....	1874	34.6	90.	48. (pass'r) 37. (fr't)
Phila. & Reading.........	1873	54.	91.	

Remarks.—On Lake Shore & Michigan Southern, only freight from Buffalo to Chicago is classed as "through." On the other hand, the Louisville & Nashville includes only way or local business proper as "local," excluding a large amount of business which would ordinarily be classed as local.

are either by law or by fixed custom, determined purely by distance, any reduction of distance would be almost certain to entail a balance of loss upon the company amounting to some cents per train for each mile saved. For example, it would undoubtedly entail a net loss upon the New York Central Railroad, so far as passenger business is concerned, to shorten their line by several miles, even if it could be done without cost to them, provided all their business, both through and way, had to be transacted over the new line. For, estimating the cost of a train mile on that road at $1.27 and taking 54 per cent. of the same, we have 69 cents as the cost of running a train an additional mile. On the other hand, taking an average load of passengers at 140, and assuming the very low proportion of one-half only, as that on which the receipts are fixed by the legal limit of 2 cents per mile, we have an average gross loss of 140 cents per train, or a net loss of 71 cents, for every mile cut out from the line. And if the gross loss had been but 10 cents instead of 140, it would have operated to *reduce* the value of any saving of distance by so much, although not entirely destroying it.

It is open to question how much weight should be given to these considerations even where rates are fixed purely according to distance; certainly it should not be so great as the bare facts might appear to justify. As a question of public policy they have no force whatever, the ultimate loss from a needless service being the same whether borne by the railway company or transferred by it to the public. And inasmuch as the prosperity of a railway is intimately connected with that of its supporting population the policy, under any circumstances, of thus inflicting an unnecessary tax upon the community for the sake of a small margin of profit may be questioned, especially as the ability to do so, through absence of competitition, is by its very nature temporary and changeable. Nevertheless, as a railway is a business enterprise and not a charitable institution, it may be policy to assign some weight to this consideration, at least to the extent of carefully avoiding an over estimate of the value of saving distance. There are very few roads on which the necessity of fixing rates according to the distance hauled is not practically operative to some extent, even if rates be not so fixed by law; and on many such the whole business of the road is practically independent of competition, while at the same time the future returns on the capital invested are at the best exceedingly problematical. In all such cases a sound policy would seem to require that the expenditure should be mainly directed, not to securing the "shortest line," but to reducing the gradients or *vertical* distances, which we shall find to be out of sight ahead of linear variations in their effect on operating expenses, but over which a railway company can under no circumstances derive additional revenue for running its trains. A discriminating public is far less willing to pay for transportation *over* a ravine or a mountain than for being carried ten miles around it.

PRACTICAL EXAMPLES OF THE VALUE OF DISTANCE.

As an example of the use of Table A, let us take one given in Prof. Vose's "Manual for Railroad Engineers," viz.: What is the value of saving one mile of distance to a road of which the total expenses for maintenance and operation are (or are expected to be) $10,000 per mile; cost of capital 6 per cent. Here we have, by the second column of Table A,

$$\$7,000 \times 10 = \$70,000$$

as the value of saving one mile. Or, if we consider the wages of all train hands to be affected *pro rata* by so small a reduction, this amount should be increased by something less than 29 per cent., and we have

$$\$70,000 \times 1.29— = \$90,000,$$

which is the justifiable excess of expenditure to construct an alternate line of any length one mile shorter than the other; and this without allowing any weight to considerations of the effect of way business.

As given in the "Manual," the justifiable expenditure to effect this saving is $206,666, an excess of from 130 to 200 per cent. over the estimate above.†

The writer conceives this rather gigantic difference to be due to two errors in the "Manual." First: In assuming (as is done throughout the chapter on location) that to operate an *extra* mile, more or less, costs as much as the *average* expenses per mile, instead of from 42 to 54 per cent. only, if our premises be sound; which accounts for from $80,000 to $100,000 of the difference; and secondly, in adding in an imaginary saving due to *not constructing the mile saved*, which accounts for the remaining $40,000 But it is very obvious that if we spend it we do not save it. By Prof. Vose's rule, a light, cheap railway doing the same business as a very costly one is not justified in expending the same sum for a given improvement, which is a reduction to absurdity. The author seems to have been naturally appalled by the magnitude of his own figures, for he adds, "in most cases it certainly *is not* advisable to make so great an expenditure in the beginning as the above figures would indicate." But *why* not, if the premises be sound and the facts as stated? The outlay which is advisable is the very fact to be determined.

In commenting on this example the author also adds: "In estimating the amount to be spent in reducing grades or curves we are of course to regard their effect on the cost of operation, the same as for simple distance, but the interest on construction, *which applies to distance, does not apply to grades and curves* " The writer regards this distinction as entirely non-existent, the interest in construction not applying in either case. Whether alternate alignments differ vertically or horizontally, it is the capitalized yearly saving *alone* which represents the *value* of one over the other; the cost of construction, balanced against this value *then enters in only for the purpose of determining whether it will cost more than it is worth.*

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† "If a railroad costs $40,000 per mile, and the cost of maintenance and operation is $10,000 per mile, we might spend $206,666" [more than on the other line] "to shorten the line a mile." (Manual for Railroad Engineers, p. 46.)

As a second illustration: What is the value to the Pennsylvania Railroad Company of cutting out one mile of their main line? This must be different at different points on the line, but we will take an average of the whole line. The expenditures for the past six years have been very nearly uniform at an average of something less than $26,000 per mile, out of which

All transportation expenses have been about....................	69.7	per cent., or	$18,120	per mile.
Repairs of rolling stock and fuel, oil, etc., have been about......	33.5	" "	8,720	"
Maintenance of way (except bridges and buildings) has been about....................	21.75	" "	5,660	"
Motive power and repairs of cars have been about...............	38.	" "	9,880	"

Then, by Table A, estimating on the basis of all transportation expenses, as the most accurate, we have, as the true value of saving one mile, assuming the rate of interest to be 6 per cent.,

$$\$18,120 \times 10 = \$181,200.$$

Determining the same value by some of the other less exact methods in Table A, for purposes of comparison, we have:

(2) Repairs of rolling stock and fuel, oil, etc..............	$8,720 × 22.6	= $197,072
(3) Maintenance of way (except bridges and buildings)	5,660 × 30.4	= 172,064
(4) Motive power (including wages) and repairs of cars......................	9,880 × 18.9	= 186,732
Total yearly expenditure per mile..........................	26.000 × $7,000	= $182,000

Or, we may estimate only on the basis of the number of trains daily, which is about 44 each way. Then, by Table A,

$$\$4,550 \times 44 = \$200,200.‡$$

We may say then that, if our conclusions are correct, the present value of cutting out one mile of track on the Pennsylvania Railroad is something over $180,000, assuming that it would involve no decrease in receipts from way business and also no decrease in train wages. If the latter were decreased in full proportion, this estimate should be increased by about 27 per cent. on this road (11×2.42), or, in round numbers, $50,000, giving $230,000 in all.

This saving has been valued by Mr. Herman Haupt (see "Considerations Affecting the Value of Distance Saved," *Van*

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‡This latter estimate should properly agree much more closely with the others, but the writer did not have the requisite information to separate main line expenses and train mileage from that on the branches. On the main line only the cost per train mile is probably somewhat less than $1.00.

Nostrand's Engineering Magazine, Vol. IV., p. 593; also *Railroad Gazette*, 1873, p. 267, and Vose's "Manual for Railroad Engineers," p. 46) at $433,000, a difference of from $200,000 to $250,000 per mile in excess of the above estimate.

This difference is due to three causes: First, the cost per train-mile on the Pennsylvania Railroad was then (1869) $1.30 per train-mile, instead of about $1.00 as at present. This alone accounts for a difference of 30 per cent. Secondly, Mr. Haupt's estimate was (although not so stated) for the value of one mile saved at *a particular point* on the line, viz.. west of Altoona, where distance is undoubtedly more valuable than for the average of the whole road. Thirdly, and mainly, Mr. Haupt's whole estimate is based upon the fallacy that all expenses which increase with *tonnage transported* increase also with the *distance transported*; and accordingly he has included several large items such as teaming, station labor, etc., which have no connection whatever with the exact length of the track, and in addition thereto has also included the *full* cost of fuel, repairs and other transportation expenses proper, of which only a portion can fairly be so included. This increases the estimate out of all due proportion, even if no other causes co-operated to do so.

If, instead of the Pennsylvania, we had selected any of the other 12 roads given in Table I., we should have obtained an equal general uniformity from the different formulæ of Table A; but to avoid any appearance of unfairness, let us take, as an *anti-illustration*, the Syracuse, Binghamton & New York Railroad, on which the percentage of the various expenses has been widely different from those we have assumed. The average of the last four years has been as follows, viz.:

For maintenance of way	47.3	per cent	$2,700	per mile.
" " engines and cars	16.1	"	920	"
" fuel, oil, etc	11.3	"	640	"
" train hands	5.7	"	330	"
" taxes and general expenses	19.6	"	1,130	"
Total expenses	100.	"	$5,600	"
Average number of trains daily				8

We obtain from these figures the following valuations of one mile saved at 7 per cent. for capital; the first being the most exact:

By column (1), Table A	$4,470 × 86	=	$38,442
By column (2), Table A	1,560 × 19.4	=	30,264
By column (3), Table A	2,300 × 26.1	=	60,030
By column (4), Table A	1,725 × 16.2	=	27,945
Per $1,000 of annual expenditure per mile	5 6 × $6,000	=	33,600
Per daily train	$3,900 × 8	=	31,200

Here is a sufficiently wide divergence indeed; yet even in this case, had the road been originally located on the basis of an estimated business of 8 trains daily as in the last line above, or on the basis of $5,500 to $6,000 per mile of annual expenditure, it would have been a sufficiently good guide for location, as the wide variation in the above estimates is probably due in a great degree to errors in the apportionment of expenses or to temporary causes. We may repeat again that if the face of returns be accepted without scrutiny and if, moreover, an average be not taken extending over a considerable period, no close correspondence can be reasonably expected with the average percentages we have adopted.

REDUCTION OF CURVATURE.

In order to conveniently estimate the cost of curvature we must determine,

1st. The number of degrees of curvature which opposes a resistance to the motion of trains equal to one mile of straight and level track; and

2d. The amount by which this increased resistance increases the several items of operating expense.

Into the first question we shall enter but briefly, accepting the results of others. Professor Vose in his "Manual for Railroad Engineers" gives "as the average of numerous experiments that the resistance on a 10° curve at 20 miles an hour is double that on a straight line." For an average rolling friction of 10 lbs. per ton (9.3 lbs. per ton is assumed by Prof. Vose at that speed, according to Clark's formula,

$$R=\frac{V^2}{171}+8),$$

this corresponds sufficiently well with the generally accepted approximation of 1 lb. per ton per degree of curvature. In the appendix to the "Manual" are given the details of the experiments by Mr. B. H. Latrobe on the Baltimore & Ohio Railroad, and by Mr. Zerah Colburn on the Erie Railway. Mr. Latrobe's experiments indicate that (at very slow speeds) a 14° curve doubles the resistance; and as a 14° curve one mile long would contain 740° of curvature, we have 740° as the amount of curvature opposing a resistance equal to one mile of straight track. Mr. Colburn's experiments (for a speed of 6 to 12 miles an hour) indicate that a 10° curve only is required to double the resistance, or 528° per mile; thus corresponding with Professor Vose's average, except that the speed is less. Molesworth's "Pocket Book of Engineering Formulæ" gives as the formula for the resistance of curves "One per cent. per degree of curvature occupied by the train." For an average train of say 700 feet in length (20 to 22 cars) this would require a 14° curve to double the resistance, thus corresponding with the experiments of Mr. Latrobe. Molesworth's formula was probably deduced from experiments on very flat curves, but on the other hand with cars having an inflexible wheel base, so that his formula might fairly be adopted for American railways.

Summing up these several formulæ, we have :

	Curve of double resistance.	Deg. of curv't'e per m.
By Latrobe's experiments, at very slow speeds.......	14°	740°
" Colburn's " " speed of 6 to 12 miles per hour..	10°	528°
" Molesworth's formula, for trains 700 feet long.......	14°	740°
" " " " " 1,000 " ".......	10°	528°
" Vose's " " speed of 20 miles an hour.	10°	527°
" " " " " " 25 " " "...	11° 20′	598°
" " " " " " 15 " " "...	9°	476°

On the authority of these different formulæ, we may assume about 600°, or a continuous curve of 11° 20′ one mile long, as consuming an amount of power equal to one mile of straight track ; the number of degrees consuming such an amount of power being less on low-grade roads running very long trains at slow speeds, and greater in proportion as the trains are shorter and the speed greater. Probably 600° is a somewhat high average, and hence leans to the conservative side by giving a somewhat low estimate of the cost of one degree.

We will consider now the second branch of our subject, viz. :

THE EFFECT OF CURVATURE ON OPERATING EXPENSES.

It is a singular fact that a very careful comparison of statistics will generally fail to show any considerable difference in the expenses per train mile on different railways, or on different divisions of the same railway, which is clearly due to differences in the amount of curvature or of rise and fall. It would lead us too far to substantiate this statement in detail ; Table I., Table XI. below, and several others in this paper, afford cumulative evidence of this fact, which has often been noticed. For example, we may quote the following testimony of the eminent English engineer, Mr. Charles B. Vignoles, formerly President of the Institution of Civil Engineers, as quoted with approval in Dempsey's "Practical Railway Engineer" (p. 11):

"Mr. Vignoles stated in a paper before the British Association for the Advancement of Science that he had analyzed railway expenses of working, and the average expenses of a train mile, as deduced from several years' experience and observation on various railways operating under different circumstances and with greatly different gradients. The result was that, on passenger and light traffic lines, the total cost of a train mile averaged 3s. per mile—2s. 6d. being the least and 3s. 4d. the greatest; and that this average seemed to hold good *irrespective of grades and curves* [the italics as quoted]. It was not found practicable to distinguish the additional expense, if any, arising from grades and curves, but as three-fourths of railway expenses were quite independent of these curves, such additions must be small."

It must be remembered, in considering such testimony, that the main expense of the *heaviest* or *ruling* gradient of a line does not appear in the form of an increased cost *per train mile*, but in the greater number of trains necessary to transact the same business. The same is also true of any curvature which is so exceedingly sharp and continuous as to limit the capacity of engines and the weight and length of trains in the same manner as heavy gradients. Nevertheless, it still remains true that nearly all curvature and all rise and fall on gradients not exceeding the ruling grade have no such effect in increasing the number of trains necessary to transact the same business, and if there exist any very grave disadvantages in ordinary curvature and rise and fall it should appear in some form capable of ready detection. We proceed now to consider the effect of curvature on operating expenses in detail, and shall find that it does so appear in the wear of rails, but in no other item of expense except fuel.

Fuel.—Under the head of "Reduction of Length" we have already seen cause to believe that 30 per cent. of the cost of fuel, viz.: 10 per cent. for getting up steam and 20 per cent. for stopping and starting and standing idle, is a constant wastage independent of the exact distance run. All of this may be considered as likewise unaffected by the resistance of curvature, and in addition thereto there is another constant source of loss, viz.: *condensation*, or radiation of heat, which varies with the time of exposure, and hence with the distance run, but is inappreciably affected by the power developed per hour. Mr. D. K. Clark (*Mechanics' Magazine*, 1856, p. 535) estimates the percentage of this loss as "increasing with the degree of expansion until in cutting off at ⅛ stroke the loss may amount to 60 per cent. of the whole steam admitted into the cylinder. * * The saving of fuel by superheating steam should be at the lowest estimate 10 per cent., and might and probably would be much greater."

Allowing only 10 per cent. for this source of waste, in addition to the 30 per cent. above, we have left only 60 per cent. of the total consumption as the proportion which increases directly with the power demanded during a given time. To lump in the whole consumption as directly increasing in proportion to momentary demands for power would lead to gross exaggeration.

Repairs of Engines and Cars.—The effect of curvature on these items is probably very slight. The following table (Table XI.) gives the average cost per mile of running engines on the Pennsylvania Railroad for a period of four years, and also on the Philadelphia & Erie Railroad (which is under the same management) for a period of three years. The several divisions of these roads differ greatly in respect to grades and curvature, yet judging by the indications of the table the cost of running engines would appear to be absolutely independent of any such differences. The same result would be reached by a comparison of the Pennsylvania Railroad proper with the United Railroads of the New Jersey Division, since their consolidation under one management, except that the pounds of fuel burned per 100 miles is considerably less on the latter, a difference in a great degree accounted for by difference in the weight and size of the engines, but doubtless resulting in some degree from the more favorable alignment of the latter. The testimony of Mr. Vignoles, already quoted, is to the same effect as the above, and the opinion has been expressed to the writer by several master mechanics that the effect of curvature on the wear of rolling stock is quite inconsiderable when the track is well maintained, unless in the wear of tires and wheels. We may estimate the increased cost on curves of moderate length and average radii, as not exceeding 1 per cent. per degree of curvature, or 11⅓ per cent. for one mile of 11° 20′ curve. On very long sharp curves, however, this percentage would probably be double, especially in the case of reversed curves.

Wear of Rails.—The relative wear of rails on curves is a subject on which the writer was unable to discover any published information whatever; but by the kindness of Mr. Jacob Keene, for many years Roadmaster of the Eastern Division of the Erie Railway, he has been furnished with the interesting and valuable statistics given in Table XII., which have a singularly close agreement with each other and enable us to form an estimate sufficiently approximate upon this subject. The statistics of the renewals of rails on several contiguous miles subjected

TABLE XI.

Showing in detail the average cost per train mile of running engines on the several divisions (differing widely in the amount of curvature and rise and fall) of the Pennsylvania and Philadelphia & Erie Railroads, Averaged on the Pennsylvania Railroad for a period of four years (1859–66–70–73), *and on the Philadelphia & Erie for three years* (1866–70–73).

DIVISIONS OF PENNSYLVANIA RAILROAD.	*Passenger Engines.*				*Freight Engines.*				*Average of Passenger and Freight.*			
	Repai's.	Fuel.	Stores.	Total.	Repai's.	Fuel.	Stores	Total.	Repai's.	Fuel.	Stores.	Total.
Eastern	6.32	6.08	1.03	13.43	6.53	7.78	1.26	15.56	6.42	6.93	1.15	14.50
Middle	10.03	6.33	1.03	17.44	7.67	7.67	1.10	16.44	8.87	7.00	1.07	16.94
Average of Eastern and Middle	8.20	6.20	1.03	15.43	7.10	7.72	1.18	16.00	7.65	6.96	1.11	15.72
Western	7.97	6.33	1.17	15.52	10.54	8.79	1.61	20.94	9.25	7.59	1.39	18.23
Mountain and Tyrone	3.91	6.70	.73	11.34	9.29	7.38	.93	17.60	6.60	7.04	.83	14.47
Average of Western, Mountain and Tyrone	5.94	6.54	.95	13.43	9.91	8.09	1.27	19.27	7.92	7.32	1.11	16.35
Average of the entire road	7.07	6.37	0.99	14.43	8.50	7.91	1.22	17.63	7.78	7.14	1.11	16.03

PHILADELPHIA & ERIE RAILROAD.

DIVISIONS.	*Average of all Engines*			
	Repai's	Fuel.	Stores.	Total.
Eastern	10.64	9.91	1.19	21.74
Middle	11.1	9.77	1.19	22.06
Western	10.49	9.92	1.15	21.56
Average	10.74	9.87	1.18	21.79

Remarks.—On the Philadelphia & Erie the expenses of engines are not kept separate for the different classes. The difference in the cost of repairs is due, as the writer learns, to the very different character and condition of engines.

to exactly the same conditions of traffic, but widely different in respect to curvature, have been kept by Mr. Keene for a period of 17 years and are given for each year in Table XII. below. Beneath them are given the details of alignment for the same miles.

Table XIII. is made up of deductions from the facts given in Table XII. Miles 12 and 52 are not included in Table XIII., as the statistics for them are imperfect, but miles 38, 39, 40, 13 and 14 are peculiarly favorable for purposes of comparison as to the wear of rails from curvature. All the four latter contain continuous sections of reversed curvature,* of varying length and radii on each mile, but nearly uniform on the same mile, while mile 38 is practically a straight line and furnishes a standard of comparison for miles 39 and 40. Miles 13 and 14, being subjected to different conditions of wear, can only be compared with each other.

With these data given, the best basis of comparison was considered to be as follows:

1st. To determine the percentage of increased wear on each mile in comparison with some other adjacent mile.

2d. To determine the fractional part of each mile which included the reversed curvature (in every case continuous, with an inconsiderable exception on mile 40) causing such difference of wear; including also in this distance the short pieces of tangents connecting the reversed curves and 200 feet of tangent at each end of the continuous curvature. These short tangents were included, as the wear on them is undoubtedly at least as great as if the curvature were continuous over them without reversing points.

3d. To determine from these two percentages what *would* have been the percentage of increased wear had the same alignment as to curvature extended over the whole of each mile. This is evidently given by dividing the actual percentage of increase by the decimal part of a mile which includes the alignment which caused it.

4th, and lastly. By dividing this latter percentage of increase by the difference in the average degree of curvature on the two miles, we have the nearly constant percentage shown in the last column of Table XIII.; which is the percent-

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* The team "reversed curvative" in this article is applied to curves connected by short pieces of tangent not sufficiently long for the train to straighten before entering on another curve. Technically these are not reversed curves, but they have all the disadvantage of the technical reversed curve, in a less degree.

TABLE XII.,

Showing in detail the renewals of rails on several miles of the Eastern Division of the Erie Railway, varying in respect to curvature, for a period of 17 *years.* (*Furnished to the writer by Mr. Jacob Keene, Roadmaster E. Div. Erie Ry.*)

Year.	Mile 38.	Mile 39.	Mile 40.	Mile 12.	Mile 13.	Mile 14.	Mile 52.
1858	0	1,260	3,699	....	....	....	....
1859	420	2,310	5,852	....	....	....	....
1860	2,230	2,356	3,716	....	....	....	....
1861	2,184	2,500	4,474	....	....	....	....
1862	5,872	2,649	1,235	....	....	....	....
1863	0	3,709	1,165	....	....	....	....
1864	3,826	20,782	2,496	....	....	....	....
1865	5,723	3,954	2,725	....	....	....	....
1866	2,471	2,373	3,748	3,800	0	4,418	....
1837	3,375	6,069	5,717	0	5,990	3,500	1,248
1868	8,962	3,681	7,658	4,720	7,736	1,624	2,496
1869	4,343	15,446	5,371	8,703	13,687	7,462	7,179
1870	8,577	4,283	8,643	6,146	6,525	3,700	0
1871	4,788	8,517	7,029	2,222	2,248	8,585	1,709
1872	2,150	9,211	5,961	570	3,470	3,516	7,922
1873	2,138	3,795	2,695	....	570	3,143	2,726
1874	0	3,942	2,556	....	1,612	973	3,847
Total	57,059	96,837	74,740	26,161	41,838	36,921	27,127
Average per year	3,356	5,696	4,396	3,737	4.649	4,102	4,069

Statistics of Alignment.

Length of tangent	5,280	1,355	1,409	4,428	3,509	3,531	....
Length of curves	0	3,925	3,871	852	1,771	1,749	....
Number of curves	0	5	4	2	3	2	....
Total number of degrees	0°	173°	107°	48°	53¼°	20¼°	....
Average degree of curvature	....	4°24′	2°22′	5°40′	3°	1°10′	....
Total length of continuous reversed curvature, connected by less than 300 ft. of tangent	None.	4,828 ft. (0.91 mile)	4,871 ft. (0.92 mile).	None.	2,401 ft. (0.454 mile).	2,247 ft. (0.425 mile).	....
Gradients	45 ft. per mile, and short section level.	11 ft. per mile, and ⅓ level.	Undulating 20 to 30 ft. per mile and level	Half level; half 25 ft. per mile.	28 ft. per mile; ⅓ level.	17 feet per mile.	59 feet per mile.
Stations	None.	None.	None.	Passaic.	Clifton.	Lake View.	Oxford.

Remarks.—**Mile** 38 is nearly straight with one slight curve for which the writer had no statistics, and partly therefore neglected ar unimportant. **Mile** 39 is a succession of sharp reversed curves. **Mile** 40 contains nearly the same length of reversed curves of longes radii.

Mile 12 includes Passaic station and has on it a 10° curve, but no reversed curvature. The lack of statistics for the last two years has evidently operated to reduce the apparent wear per year, and it is therefore not used for comparison in Table XIII. below. **Mile** 13 has on it the "weazel curves," so termed, a sharp double reverse, without apparent necessity. **Mile** 14 has a single reverse of longer radii.

Mile 52 gives statistics for the down track only (on 60 feet grade), the up track having been laid in 1867 with John Brown steel rails, which are still (June, 1876) in use. The up track on the same mile was relaid with the number of feet of iron rail given above (mainly Trenton iron) until September, 1874, when the down track also, as well as all the other miles given above, was relaid with steel rails. This mile is not used for comparative purposes in Table XIII.

All the above miles were in September, 1874, relaid with steel rails.

Miles 39, 40, 13 and 14 of the above table have all their curvature combined in a continuous succession of reversed curves connected by short pieces of tangent; the average length of the latter, on each mile, varying nearly in proportion to the average degree of curvature.

age of increased wear of rails, per degree of curvature, on continuous reversed curves connected by short pieces of tangent, the latter varying in length nearly in proportion to the radius, but in no case sufficiently long for the train to straighten before entering on a new curve.

It will be readily admitted that this is the most trying description of curvature, unless it be reversed curves without *any* connecting tangents. How the wear of rails on long continuous curves of the same radii would compare with short reverses of the above description is a matter of opinion, but it is undoubtedly much less than in the latter case, even although the number of degrees of curvature in a given distance would be somewhat greater. That this is presumably so, we might show by another method of considering the above statistics, but that the writer fears to exhaust the patience of the reader. On curves of moderate length ending in long tangents probably the wear of rails would not amount to half that shown in Table XIII. The statistics for mile 12, in Table XII. give ground for this belief, and the writer has learned on inquiry that the recent experience of the Baltimore & Ohio

TABLE XIII.,

Showing the Percentage of increased Wear of Rails on Continuous reversed curves connected by short tangents, as deduced from the statistics of renewals on the Erie Railway, Eastern Division, given in Table XII.

Miles compared.	Average renewals per year.	Difference in yearly renewals (caused by curvative).	Percentage of increase caused by curvature.	Total length of continuous reversed curvature. (Miles.)	Per centage of increase in renewals if curvature had been contin'd over ent. mile.	Average degree of curvature.	Difference in same.	Percentage of increased wear of rails PER DEGREE OF AVERAGE CURVATURE.
38 39	3,356 5,696	2340	70.	.91	77.	0.0° 4.4°	4.4°	17.5
38 40	3,356 4,396	1040	31.	.92	33.6	0.0° 2.37°	2.37°	14.2
39 40	5,696 4,396	1300	29.5	.915(av.)	32.5	4.4° 2.37°	2.03°	16.0
13 14	4,649 4,102	547	13.3	.44 (av.)	29.2	3.0° 1.17°	1.83°	16.0
AVERAGE PERCENTAGE OF INCREASE IN WEAR OF RAILS, PER DEGREE OF AVERAGE CURVATURE, on continuous reversed curves, connected by short tangents not exceeding from 100 to 300 feet in length								16.0

Railroad would indicate the wear of rails on ordinary curves to be only 4 or 5 per cent. per degree of curvature. Taking an average of long and short curves, we may safely assume the wear of rails to be somewhat less than 10 per cent. per degree of curvature, or 100 per cent. for one mile of 11° 20′ curve. This percentage, however, would be increased by 50 or 100 per cent. in the case of continuous short reversed curves, similar to the alignments considered above.

TABLE B.,

SHOWING THE CAPITALIZED VALUE OF SAVING ONE DEGREE OF CURVATURE; FOR CURVES OF MODERATE LENGTH AND AVERAGE RADII.

RATE OF INTEREST ON CAPITAL	*Projected Lines.*		*Railways in Operation.*			
	For each estimated daily train (round trip) over the line (assuming $1 per train mile).	For each estimated $1,000 of yearly expenditure per mile.	Multiply the average annual expenditure per mile for any one of the following items by the number given below it opposite the proper rate of interest.			
			All "transportat'n" or "line" exp'ses.	Maintenance of way, including all expenses.	Maintenance of road bed and track only including iron.	Maintenance of road bed and track, including iron, and fuel, oil, &c.
5 per cent......	$4 87	$7 50	.0107	.0278	.0326	.0214
6 "	4 06	6 25	.0090	.0232	.0272	.0178
7 "	3 48	5 36	.0077	.0199	.0233	.0153
8 "	3 05	4 69	.0067	.0174	.0204	.0134
10 "	2 44	3 75	.0054	.0139	.0163	.0107
YEARLY COST of 1° of curvature...	$0.244	$0.375	.00054	.00139	.00163	.00107

REMARKS.—If the cost per daily train be higher or lower than $1, the value PER DAILY TRAIN given above must be multiplied by that assumed cost.

For sharp reversed curves, connected by tangents not sufficiently long for the train to straighten, these values should be increased by a maximum of 50 to 100 per cent. and for very short curves of long radii reduced in nearly equal proportion.

Track Maintenance and Ties.—How much greater the cost of these items may be on curves the writer has not been able to determine by any statistics, but estimates which he has secured from several very competent sources have not varied far from an average of 4 or 5 per cent. increase per degree of curvature, in all road-bed and track expenses except rail renewals. This is equal to say 50 per cent. increase on one mile of 11° 20′ curve.

Summing up these various items, we have, as the cost per train mile of an amount of curvature opposing a resistance equal to one mile of level track (which we found to be 600°):

Items.	Total cost of item at $1.00 per train mile.	Proportion of same increasing with curvature.	Increased cost from a double resistance (600°).
Fuel ...	10 cts.	60 per cent.	6. cts.
Oil, waste and water	2 "	50 " "	1. "
Repairs of engines and cars	19 "	11⅓ " "	2. "
Renewal of rails	7 "	100 " "	7. "
Maintenance of road-bed and track	13 "	50 " "	6.5 "
Maintenance of yards and structures	7 "	Unaffected	0. "
Train wages, station and general expenses	42 "	"	0. "
Total	$1.00	22.5 per ct.	22.5 cts.

Expressing the above cost per train mile for 600° in the form of the cost of 1° per train mile or per daily train, we have:

$$\frac{\$0.225}{600} = .0375 \text{ cts.} = \text{cost per train mile of } 1^\circ \text{ of curvature.}$$

$$.0375 \text{ cts.} \times 650 = 24.375 \text{ cts.} = \text{cost per year per daily train of } 1^\circ \text{ of curvature.}$$

This latter sum, divided by the rate of interest on capital, gives the capitalized value of saving 1° of curvature, which is given in the first column of Table B below:

In the case of railways in operation, for which exact statistics of expenses are attainable, we may express the value of saving 1° of curvature in any one of the following ways; the principle being the same as that already followed in estimating the value of distance:

The yearly cost of 1° of curvature is

$\frac{.0375}{100}$, or .000375 times the average yearly TOTAL EXPENSES per mile.

$\frac{.0375}{70}$, " .000536 " " 'Line' or 'Transportation' "

$\frac{.0375}{27}$, " .00139 " " Maintenance of Way "

$\frac{.0375}{23}$, " .00163 " " do. of Roadbed and Track (including iron) "

$\frac{.0375}{35}$, " .00107 " " do. + Fuel, Oil, etc., " The amounts, or percentages, in the second column above, multiplied by the yearly expenditure per mile for the item opposite to it, give the yearly cost of 1° of curvature. Or, if they be first divided by the rate of interest on capital, .06, .07, etc., they will, when multiplied by the yearly cost per mile of the item opposite them, give the *capitalized value* of saving 1° of curvature. We thus obtain the latter columns of Table B below:

TABLE B.

"EQUATING" FOR CURVATURE.

The cost per year per daily train of 1° of curvature is (as estimated above)	$0.244
The cost per year per daily train of 1 mile of distance is (as previously estimated according to the same standard)	$273.00
The cost per year per daily train of 1 foot of distance (as previously estimated according to the same standard)	$0.0517

Accordingly, 1° of curvature $= \frac{.244}{.0517} = 4.7$ feet of distance,

and 1 mile of distance $= \frac{273}{.244} = 1{,}120°$ of curvature.

On the construction of the Pennsylvania Railroad 1° of curvature was estimated as the equivalent of 5 feet of distance, and 1,056° of curvature as equal to 1 mile. Mr. J. C. Trautwine (as quoted by Prof. Vose, "Manual for Railroad Engineers, p. 46, from which source the preceding fact was also ascertained) estimates 1° of curvature as equal to 8.7 feet of distance; but this is on the assumption that two-thirds of the annual operating expenses are in direct proportion to the motive power expended, a very excessive estimate which is not true even of the cost of fuel. Prof. Vose's own figures (p. 43) are equivalent to estimating that 1° is equal to 3 feet at a speed of 15 miles an hour and only 2.1 feet at a speed of 30 miles an hour; or only about ¼ of that quoted from Mr. Trautwine.

PRACTICAL EXAMPLES OF THE VALUE OF CURVATURE.

As an example arising in original location, we may take the following, given in Vose's Manual for Railroad Engineers (p. 43):

Line A, 100 miles long, contains 4,216° of curvature.

Line B, 98 miles long, contains 8,432° of curvature.

Required, the value of one line over the other per estimated daily train, and also their "equated length."

Here we have:

In favor of A, 4,216° of curvature, @ $3.48 per daily train (by Table B)	$14,671 68
In favor of B, 2 miles of distance, @ $3,900 per daily train (by Table A)	7,800 00
Balance, showing the value of line A over line B, per daily train	$6,871 68

Accordingly, for an estimated business of 10 trains daily, each way, over the line, we shall be justified in expending $68,700 more than the cost of line B to construct line A; as, for so small a difference in length, the item of train wages would probably be in no way affected. If it varied in exact proportion, the balance in favor of A would be reduced by about one-fourth.

'Equating' these same lines, we have

$$\text{Line A, } 100 + \frac{4{,}216^\circ}{1{,}120^\circ} = 103.76 \text{ miles}$$

$$\text{Line B, } 98 + \frac{8{,}432^\circ}{1{,}120^\circ} = 105.52 \text{ miles}$$

Balance in favor of A, 1.76 miles, at $3,900 per daily train = $6,864.00,

thus substantially agreeing with the direct estimate above.

In the "Manual" the equated length of these two lines is given as exactly the same (viz., 102 miles) and this notwithstanding the fact that the cost of an amount of curvature equal in resistance to one mile of straight track is there estimated somewhat higher than we have done above, which should have tended to make the balance in favor of line A still larger. The cause of this difference, without here going into details, is that throughout the chapter on location in that volume the value of lines in respect to distance is assumed to be in direct proportion to the measured lengths, whereas we have seen that the *average* expense per mile of road is more than twice the *additional* cost arising from an additional mile. The comparative values of the above lines, independent of curvature, is as 98 to less than 99, instead of 98 to 100.

As a second example: What would be the present value to the Erie Railway Company of saving two miles of distance and 300° of curvature on the Eastern Division?

The operating expenses averaged for the whole main line, neglecting branches entirely, are about $30,000 per mile. On the Eastern Division, for lack of definite statistics, we may assume it to be nearly or quite $40,000 per mile. Out of this sum, Maintenance of Way is, by Table I., 24.5 per cent., or $9,800 per mile, and the entire "Line" or transportation expenses proper 72.3 per cent., or $28,920.

Then, by Table B, we have as the cost of 300° of curvature—

Per $1,000 of yearly expend're per mile,	300° × $5.36 × 40	= $64,320
Per Maint. of Way " "	300° × $9,800 × .02	= 58,800
Per "Line" or "Transportation" expenditure per mile	300° × $28,920 × .0077	= 66,805

The variation measures the amount by which the actual percentage of various expenses differs from the average we have assumed. If the percentages were determined, however, by the experience of any one year, the variation would undoubtedly be greater.

The value of distance on the Erie Railway, as measured by the various standards given in Table A, would vary in about the same proportions as above. Estimated per $1,000 of yearly expenditure per mile we should have, as the value of two miles, at 7 per cent. for capital:

$6,000 × 40 × 2	$480,000
Add for 300° of curvature, say	60,000
Total present value of the assumed change of line	$540,000

This very large amount, it must be remembered, is an estimate on the conservative side in every respect (unless, possibly, in the assumed aggregate expense per mile on the Eastern Division), and represents the amount which it is *certainly* justifiable to expend for such an improvement. As the value of such changes is frequently estimated it would have amounted to nearly or quite $1,000,000, if not more. We shall have occasion to return to this valuation hereafter, in considering the subject of gradients.

As another example: During the construction of the Buffalo, New York & Philadelphia Railway, a change of alignment was made near Arcade station, which increased the length of the line 2,476 feet and increased the amount of curvature 128°. The change was made partly to secure a better crossing of Cattaraugus Creek and partly to secure a town subscription. On the basis of the present business of the road, what net saving to the company was required to justify this deflection?

The business of the road, by the reports of 1874, was about 2.1 passenger trains and 2.8 freight trains daily, or say 5 trains in all. The aggregate operating expenses per mile were about $3,260.

Then, by the standard of the number of daily trains, we have, assuming 7 per cent. as the cost of capital:

Value of 2,476 feet distance, (by Table A) 2,476×$0.74×5....	$9,161 20
Value of 128° curvature, (by Table B) 128×$3.48×5.........	2,227 20
Total difference in value of the two lines.............	$11,388 40

Estimating on the basis of the yearly expenditures per mile, we have :

Value of 2,476 ft. distance, (by Table A) 2,476×$1.14×3.26...	$9,201 80
Value of 128° curvature, (by Table B) 128×$5.36×3 26......	2,236 73
Total difference in value of the two lines.............	$11,438 53

The aggregate difference in the cost to the company of the two lines was at least $50,000 in favor of the longer. We therefore see that a just estimate leaves little doubt as to the preferable line, although the longer and cheaper one was adopted only after much hesitation.

NOTE ON REDUCTION OF RADIUS OF CURVATURE.—Experiment seems to indicate that the cost per degree of curvature is very nearly independent of the radius (within moderate limits) except for the difference in the length of the line *via* curves of different radii. This latter difference is, of course, given directly by the surveys of each line which are necessary to compare the cost of each, but a determination of this difference beforehand has its occasional convenience, if only as a check on the chaining, and may be very simply expressed as follows :

Let l=length of longer curve,
l'=length of shorter curve,
d and d'=degrees of curvature of each,
T and T'=length of tangents to each:
then, $l : l' :: d : d' :: T : T'$,

$$l' = \frac{d}{d'}l, \text{ and } T' = \frac{d}{d'}T$$

$$T - T' = \left(1 - \frac{d}{d'}\right)T.$$

Letting L=the length via shorter curve from T. P. to T. P longer curve,

$$L = l' + 2(T - T') = \frac{d}{d'}l + 2T\left(1 - \frac{d}{d'}\right)$$

$$L - l = 2T\left(1 - \frac{d}{d'}\right) - \left(1 - \frac{d}{d'}\right)l$$

$$= (2T - l)\frac{d' - d}{d'}$$

But the value cf $2T - l$, for a d° curve is to its value for a 1° curve as $\frac{1}{d}$. Consequently, tablulating $(2T - l)$ for a 1° curve, we have as *the difference in the length of any two curves of d and d' degrees, connecting the same tangents,*

$$\text{tabular number} \times \frac{1}{d} \times \frac{d'-d}{d'}$$

$$☞ = \text{tabular number} \times \frac{d'-d}{d'\,d}.$$

Table XIV, below, is such a tabulation for even angles between tangents. For any odd angle between tangents the tabular number is simply the difference between the length of a 1° curve of that angle and the length of its two tangents. This may be determined by inspection from the excellent table of tangents in Cross's Field Book, or is given by the formula—

$$\text{tabular No. for Table XIV} = \text{tan. } \tfrac{1}{2}\, I \times 5730 \times 2 - 100\, T.$$

TABLE XIV.

Showing the difference in length of line via any two curves of different radii, connecting the same tangents.

Rule.—*Multiply the tabular number by the* $\frac{\textit{difference}}{\textit{product}}$ *of the two degrees of curvature.*

Angle between tangents.	Tabular number.	Angle between tangents.	Tabular number.
10°	2.64	80°	1,616.1
20°	20.74	85°	2,001.1
30°	70.6	90°	2,459.3
40°	170.1	95°	3,006.4
45°	246.8	100°	3,657.6
50°	343.8	105°	4,435.0
55°	465.6	110°	5,404.4
60°	616.4	115°	6.488.6
65°	800.8	120°	8,649.4
70°	1,024.3	125°	9,514.4
75°	1,293.5	130°	11,576.2

Example: Required the difference in length between a 2° and 6° curve, connecting tangents at an angle of 100°.

$$\frac{6-2}{6\times 2} = \frac{1}{3} \times 3{,}657.6 = 1{,}219.2 \text{ feet.}$$

Value of the difference for each $1,000 of yearly expenditures per mile at 7 per cent. (by Table A)

$$1{,}219.2 \times \$1.14 = \$1{,}390.$$

☞ For any other angle, *I*, than those given above, the tabular number is given by the formula, tan. ½ $I \times 5{,}730 \times 2 - 100\, T$ = difference between the length of a 1° curve and the length of the tangents thereto.

Example: Required the difference in length between a 2° 42′ curve and a 7° 18′ curve, connecting tangents at an angle of 52° 48′, (52.8°):

$$\tan. 26°24' = 0.4964 \times 5{,}730 \times 2 = 5{,}688.74 - 5{,}280 = 408.74 = \text{Tab. No.}$$

$$\text{then, } \frac{7.3 - 2.7}{7.3 \times 2.7} = \frac{4.6}{19.71} \times 408.74 = 95.40 \text{ feet.}$$

REDUCTION OF RISE AND FALL.

The expense of gradients arises from two causes which are totally distinct and must be kept so to form any correct estimate of their cost or of their proper adjustment.

The FIRST of these is the direct cost of ascending to or descending from any given elevation instead of running on a level; in other words, the cost of RISE AND FALL. This is the branch of the subject we now propose to consider. We shall find the objection to gradients on this account to be (comparatively speaking) very small, and to lie mainly in the greater consumption of fuel.

The SECOND objection to gradients is the effect which the MAXIMUM OR RULING grade has to increase the cost of operating the entire line (however short the ruling grade itself may be) by limiting the number of cars to a train. This objection to gradients is greatly more important than the other, but it has no real connection with it whatever, being different both in its nature and in its effect in detail on operating expenses. In fact it is not, properly speaking, an attribute of gradients at all, except that, owing to the limitations of the locomotive engine, gradients *happen* to be the *most usual* cause which limits the weight of trains. But this is not invariably so. For example, the Hudson River Railroad probably approaches the nearest to being on a dead level throughout of any railway of its length in the world; yet the locating engineer has freely introduced upon slight occasion short gradients of 15 to 25 feet per mile, which could have been avoided with slight expense; and wisely so, because the unavoidably sharp curvature of the line effectually limits the weight and length of trains to such as is easily handled by the locomotive on a considerable gradient. Up to a certain grade, therefore, curvature takes the place of gradients as a limiting agent. Had the topography of the Hudson River permitted such an alignment as that of the Canada Southern Railway, for example, which has no curvature to speak of, a very great expenditure might have been justifiable to eliminate these same gradients which have thus been freely and wisely introduced. And if at some time in the future the locomotive engine should be so improved, or such a new motor discovered, as to be able to exert an indefinitely varying power at different points of the line, at the same cost per unit of force (even if the cost per unit of force were no less than at present), all objection to both grades and curvature, except such as is *inherent* in them, viz., their effect upon wear and tear and consumption of fuel, would disappear, and they might be introduced with comparative freedom; for neither of them would then have, in addition to their own *inherent* disadvantages, the further effect of limiting the weight of trains.

This distinction is readily enough admitted in the abstract, but it is frequently confused in practice; and such a practical confusion of these two distinct problems destroys the value of many discussions and estimates on the subject of gradients, and forbids any clear understanding of their proper adjustment. The two are so totally distinct that any attempt to estimate or "equate" for both of them together prevents the attainment of any formulæ for either which will hold water under the slightest examination, and, from an unconscious neglect of one or the other of them, usually leads on the one hand to preposterous theories that "undulating gradients," or surface roads, cost little more to operate than a dead level (which in some cases, on some parts of a line, is very nearly the case), and on the other hand to equally preposterous expenditures to introduce as long and as nearly level grades as possible at all points of a line indiscriminately. The latter is an inveterate weakness of many engineers who ought to know better, and who will doubtless be the first to disclaim it. Habit has made it a second nature to reduce all grades as much and as speedily as possible and to stretch out the longest piece of thread which can be made to lie on the profile in fixing the gradients. A thousand feet further is not far *on the profile*, but it often entails a considerable expense for construction to no purpose whatever; an expense which does not *show* much, to be sure; but the money thus wasted in driblets expended at a single point would often suffice to considerably reduce the ruling grade of the line. This extremely mistaken policy is especially conspicuous in the not uncommon practice of breaking a ruling grade at the earliest possible moment and stretching it out along the hillside so much the further, instead of striking a low grade and cheap construction in the bottom lands as speedily as possible by running down into the valley on the maximum grade. If there was room here for some miles of profile, the writer might adduce a brilliant example of this wise procedure on a recently constructed railway in Western New York. A certain amount (and a very small amount) of expenditure is always justifiable to reduce the rate of any grade, even although it may be less than the rate of the maximum grade. We shall find out this amount in the course of the present article, but it is far too small to justify any considerable difference in cost of construction.

We propose, then, to consider for the present the cost of RISE AND FALL *only*. This cost is, approximately speaking, directly as the vertical elevation attained and independent of the *rate* of grade. The expense arising from the MAXIMUM or RULING GRADE, on the contrary, is directly as the rate of grade and nearly independent of its length or of the vertical elevation reached.

DEFINITION OF "ONE FOOT OF RISE AND FALL."

Every foot of rising grade involves a corresponding descent at some other point on the line, except the difference of level in the termini, if there be any. In the former case a train, in going and returning, passes over two feet of ascent and two feet of descent for every foot of elevation attained, and we shall understand by the term "one foot of rise and fall" such a foot of elevation or summit, which involves both an ascent and descent in every trip. In the case of the difference of level in the termini, a train, in going and returning, passes over but *one* foot of ascent and one foot of descent for every foot of elevation attained, instead of two, and hence the cost will be only half as great. It will be obvious, therefore, that we may compare any two lines in respect to rise and fall by simply taking the feet of ascent and descent indiscriminately from the profile and dividing the same by two to determine the feet of rise and fall. No separate estimation of rise and fall in opposite directions is at all necessary, nor any consideration of the rate of ascent or descent, unless minute accuracy is desired. Certainly this is not necessary for comparing two approximately similar lines.

To estimate the cost of rise and fall, as in estimating the cost of curvature, we must, FIRST, determine the number of feet of rising grade which opposes a resistance equal to one mile of level track; and, SECONDLY, the increased expense arising from such resistance.

AMOUNT OF RISE AND FALL EQUAL IN RESISTANCE TO ONE MILE OF LEVEL TRACK.

An approximate solution of the first problem is easily reached. It is evidently given by the number of feet per mile in the grade on which a train will just maintain its motion at a given speed, assisted by gravity alone; in other words, what is termed the angle of friction. The accelerating force of gravity is given by the formula—

$$\frac{\text{rate of grade per mile}}{5{,}280} \times 2{,}000.$$

The retarding force of the rolling friction is, by the formula of D. K. Clark, generally accepted for lack of a better,

$$\frac{v^2}{171} + 8,$$

in pounds per ton of 2,240 lbs., v representing the velocity in miles per hours; or, per ton of 2,000 lbs. we may approximately enough adopt the form

$$\frac{v^2}{200} + 7.3$$

as a sufficient approximation*. Forming an equation between these two formulæ, we shall obtain (see also Vose's Manual, p. 43), at a speed of 15 miles per hour, something over 22 feet per mile as the grade offering a double resistance, and, at a speed of 30 miles per hour, something over 31 feet. For an average business of two passenger trains to one freight train, we should have an average speed of 20 miles per hour and a grade of something less than 25 feet per mile as the grade opposing a resistance to trains equal to that of one mile

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* Exactly, Clarke's formula becomes, for tons of 2,000 lbs.,

$$\frac{v^2}{181.52} + 7.14.$$

To correspond with the above approximation the original formula should have been, for tons of 2,240 lbs..

$$\frac{v^2}{178} + 8.16.$$

Very slight objection can reasonably be made to such a difference. The "171" of the formula is rather an absurb refinement.

of level track, and we may adopt this as our standard. It corresponds to an average rolling friction of about 9.3 lbs. per ton.†

INCREASE IN OPERATING EXPENSES FROM RISE AND FALL.

Fuel.—The cost of fuel, which we have hitherto considered first, we will take up after determining the effect of rise and fall on the other operating expenses.

Repairs of Engines and Cars.—That the increase in repairs of rolling stock is a very small one, per 25 feet of rise per mile, is evident from the statistics given in Table XI. in the article on curvature, showing the cost of running engines for a series of years on the several divisions of the Pennsylvania Railroad. No appreciable effect on the cost per mile run of repairing engines is visible in the statistics of the separate divisions, which differ greatly in respect to grades and curvature. As there are long and heavy grades in the mountain divisions of that road, conjoined with heavy curvature, there should certainly be *some* difference perceptible if the effect of such grades and curves on these items were of much importance. Undoubtedly the increased wear is compensated for in some degree by lesser speed and more careful handling, but as this costs the company nothing except the slight delay, we may fairly allow it as an offset to some extent; and even without doing so an estimate of 5 per cent increase in the total cost per mile of repairs of rolling stock, for each 25 feet of ascent, and the same on the corresponding descent, is probably ample. On 100 feet grades this would amount to 20 per cent. per mile of ascent, or, taking an average of the mountain divisions of the Pennsylvania Railroad, a difference of at least 15 per cent. should be visible, whereas in fact there is none at all which is clearly due to the alignment. On the Baltimore & Ohio Railroad the difference in the cost per mile of running engines should be at least 20 per cent., but the writer is informed that there is no such difference, even without allowing for the heavier class of engines employed on the mountain divisions, for which the expense should properly be somewhat greater. In this connection (and also in respect to the wear of rails on grades), we may also refer to the testimony of the eminent English engineer, Mr. Charles B. Vignoles, already quoted under the head of curvature.

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† As we have adopted 600° of curvature and 25 feet of rise and fall as each equal in resistance to one mile of level track, it follows that 1° of curvature should be equal in resistance to 0.042 feet of rise and fall $\left\{\frac{25}{600} = 0.0417\right\}$, which should accordingly be the average reduction in grade per station per degree of curvature necessary to compensate for the resistance of curves. Professor Vose's formulæ, in the "Manual for Railroad Engineers," require 0.046 per degree of curvature for this reduction; the ordinary allowance in practice (according to the writer's experience) is 0.05; and the experiments of Mr. Charles Ellet on 296 feet grades and 19° curves (300 ft. radius) would indicate nearly 0.1 per station as the requisite reduction per degree of curvature on such grades, or nearly 0.06 with oiled flanges and specially designed tank engines. Our estimate thus appears low, and probably is less than a proper allowance for this purpose; but it does not follow that the resistance of curvature has been under-estimated or that of gradients over-estimated. What we require for our present purpose is a *fair average* for all trains and all conditions of track, but in reducing grades for curvature the reduction should be sufficient to compensate for the resistance with the longest trains and under the most unfavorable circumstances.

Wear of Rails and Track.—The effect of grades on the wear of rails is greatly exaggerated in popular belief, for want of a proper distinction between the effect of a heavy *ruling* grade, on which the number of trains is increased, and the effect of rise and fall simply, on which the number of trains is the same as on adjacent pieces of level track. We shall see reason to believe that in the latter case the effect of gradients on wear of rails is very slight.

Tables XII. and XIII., in the chapter on reduction of curvature, giving statistics of the renewals of rails on the Erie Railway for a long period of years, afford one evidence of this. By reference to the tables it will be seen that, neglecting any effect from the difference in gradients, the increased wear of rails due to curvature on miles 39 and 40 amounted to the very large percentage of 16 per cent. per degree of average curvature over mile 38, which is nearly straight, but on a descending gradient of 45 feet per mile, whereas on miles 39 and 40 the grades were very light. Now if the higher grade on mile 38 had the effect of increasing the wear of rails to any considerable extent, say by as little as 10 per cent. for example, this already large percentage would have to be increased by from ¼ to ½; or, instead of 16 per cent., the wear of rails from curvature would be as much as 20 to 24 per cent. per degree of average curvature, which would certainly seem to be very excessive. We may show the effect of such an allowance for wear on grades in a little table, as follows:

Mile.	38	39	40
Alignment...............	Tangent.	4°24′ reversed curvature.	2°22′ reversed curvature.
Gradients......	45 ft. per mile.	11 ft. per mile and level.	Undulating, 20 and 30 ft., and level.
Average yearly renewals.	3,356 feet.	5,696 feet.	4,396 feet.
Percentage of increased wear due to curvature.	....	70 per cent.	31 per cent.
If we allow the wear of rails on mile 38 to have been increased by 10 per cent. over miles 39 and 40 on account of the steeper grade, the yearly renewals on mile 38 would have been (except for the grade) only..................	3,020 feet.	....	....
Consequently, the increased wear due to curvature on miles 39 and 40 would have been..................	....	88 per cent.	46 per cent.
Or, the apparent effect of curvature on the wear of rails would be increased by about....	....	¼	⅛

The very heavy grades (105 and 116 feet per mile), and large traffic of the Baltimore & Ohio Railroad, afford an admirable test of this question, and to a letter of inquiry as to the difference in the life of rails, and in the total increased cost of "Repairs of Railway" (or maintenance of road-bed and track), observed on the heavy grades of that road in comparison with level track sustaining the same engine mileage, the writer received the following reply (from Mr. W. N. Bolling, Engineer of Bridges and Permanent Way):

> "'1. What difference in the life of the same quality of rails has been observed on your 105 and 116 feet grades compared with level track sustaining the same engine mileage?'
>
> "The observations on steel rails have not been continued through such a term of years as to state definitely the difference; so far as observed, the difference is slight. With iron rails, the difference was—say 20 to 25 per cent. The conditions of use were different, however. The wear incident to grade is compensated for, in great measure, by reduced speed as compared with levels, and by a firmer road-bed, on account of better drainage.
>
> "'2. At what would you estimate the total increased cost of "Repairs of Railway" on your heaviest grades, compared with light grades or levels sustaining the same engine mileage?'

"There is but slight increased cost of repairs of railway attributable to grade, especially with steel rails. The increased cost on the heavy grades is incident to their location and not to rail wear."

In respect to the distinction in the latter paragraph it will appear, at first sight, that the use of steel or iron rails does not affect the *relative* cost of rail renewals on gradients, but consideration will show the point to be well taken. Thus, supposing the life of rails on a 105 feet grade to be only half as great as on a level. Owing to the long life of steel rails, the interest on their cost would, in their case, eat up more than half of this difference. The closing distinction in the above quotation also is one that should be kept in mind in considering the relative cost of heavy grades. Such grades are usually located in rugged and difficult country, and the increased expense arising from *that* cause is very apt to be attributed to the effect of the gradients themselves.

As operating against these facts, which tend to diminish the importance of the effect of gradients on the wear of rails and track, we will now consider the widely quoted facts as to the relative wear of rails on grades and levels on the Great Northern Railway of England, which are given in the able and elaborate paper of Mr. R. Price Williams before referred to, ("Maintenance and Renewal of Permanent Way," Proc. Inst. Civ. Engrs., Vol. XXV., 1866). The gist of Mr. Williams' argument as to the wear of rails on grades is embodied in the following statement; that the same rails on a down grade of about 42 feet per mile were renewed in three years, after sustaining a traffic of only 65,500 trains or 13,500,000 tons, whereas at another point of the line, on a level, they were renewed only after 7¼ years, having sustained the traffic of 203,000 trains or 38,800,000 tons. In another part of the paper Mr. Williams gives statistics for a similar up grade at a third point on the line, showing that rails of the same quality were still sound after sustaining the traffic of 119,500 trains ar 24,700,000 tons. From these statistics Mr. Williams concludes that the wear of rails is considerably increased on grades and is very much greater on down grades than on up grades.

If there were no other contravening facts, these statistics, critically examined, prove too much. It is altogether incredible that there should be any such difference as 312 per cent. $\left\{\frac{203,000}{65,000}\right\}$ in the wear of rails on a level and on a 42-feet grade. Such a difference would require the 116-feet grades of the Baltimore & Ohio Railroad to wear out rails 8 or 9 times as fast as on adjacent lines $\left[312 \text{ per cent.} \times \frac{116}{42} = 862 \text{ per cent.}\right]$, and would bankrupt half the high-grade railways of the world. If we consider further that the whole argument of the paper on this point is based upon the statistics of a single renewal at widely separated points of the line, it will appear *prima facie* that this affords rather an insecure basis for such important deductions, and that the very great differences reported might have been and probably were caused, or at least assisted, by external causes. So far as the asserted greater wear on the down incline is concerned, the concluding discussion to the paper itself affords conclusive evidence that this is the case, and as the facts and deductions of the paper in this respect have been widely reprinted and accepted, and contravening facts in the discussion apparently overlooked entirely (*e. g.*, see Vose's "Manual for Railroad Engineers," Appendix on Wear of Rails), it will be well to reprint the following extract in full from the discussion on Mr. Williams' paper :

> "MR. T. E. HARRISON.—As to the asserted additional wear of the rails on a down incline, no doubt when running down an incline the rails have a tendency to go down the incline themselves. But having lately examined the diagrams—which have been kept for many years and were similar in principle to those exhibited—showing the wear of rails and the dates at which they were renewed on every portion of the Northeastern Railway, he found that though on some of the inclines (the steepest being 1 in 120) there was a slight difference in the wear of the down line, yet it was so slight that he thought the increased wear in the down incline on the Great Northern Railway could not be attributed to the fact of its being on an incline, but it appeared to him to be owing to the much heavier weight of the traffic to London, including the whole of the large mineral traffic. There was a further cause which, on the Great Northern Railway, might have had the same effect, viz.: the repeated stoppages of trains which he had noticed, at the very numerous tunnels, in descending to London." (Proc. Inst. Civ. Eng'rs, Vol. XXV., p. 413.)

In a case of this kind negative testimony is of more value than positive, since a theory if sound will agree with *all* the facts, and hence this testimony completely oversets the theory of a greatly increased wear on down inclines. We have left then, out of the statistics given in Mr. Williams' paper, only the fact that rails worn out on a level by the passage of 38,000,000 tons were *not* worn out, at the date of the paper, by the passage of 24,700,000 tons on an up grade at another point on the line. This affords a very small basis for a high estimate of the wear of rails on grades, even if the statistics were not affected by any of the exterior causes which we see must have necessarily operated in the other case.

Taking all these facts which have been given into consideration, it would appear to be a fair estimate to allow 5 per cent. per 25 feet of rising grade, and the same on the corresponding descent, or 10 per cent. for each 25 feet of RISE AND FALL, as the increased cost of wear of rails, and the same allowance as the increase in the aggregate cost of maintenance of road bed and track. On a 100 feet grade this would give a difference of 20 per cent. in the aggregate of these items.

We have, then, besides the additional cost for fuel, the following as the increased cost per train mile arising from 25 feet of rise and fall:

	Total cost of item at $1.00 per train mile.	Proportion of same increasing with rise and fall.	Cost per train mile, of 25 feet of rise and fall.
Repairs of engines and cars....................	19 cts.	5 per ct. × 2	2 cts.
Maintenance of rails, road bed and track..........	20 "	5 " × 2	2 "
Train wages, maintenance of yards and structures, and station, terminal and general expenses..	49 "	unaffected.	
Total, excluding fuel and oil....................	88 cts.		4 cts.

We will now consider the effect of rise and fall on the consumption of fuel.

Fuel.—Under the head of curvature we have seen that only about 60 per cent. of the consumption of fuel is directly in proportion to the power demanded after the train is once in motion, the remaining 40 per cent. being consumed while getting up steam, standing idle, stopping and starting, and in supplying the waste from radiation, which is very nearly the same whatever the pressure or the amount of steam passing through the cylinders in a given time. As the conditions are precisely the same in the case of rise and fall, we may assume that the consumption is increased by only 60 per cent. of the average consumption per mile by every 25 feet of ascending grade. In other words, if the total average consumption in running a given distance on a level were 10 tons, it would be only 16 tons if it were a continuous ascending grade of 25 feet per mile, which requires a double expenditure of power. We may also assume that this increased consumption is the same per foot of ascent whether the rise be concentrated on one mile or spread over ten; it being understood of course that we are not now considering the effect of such grades as demand an expenditure of power beyond the capacity of the engine, thus carrying us into the subject of maximum or ruling grades.

In descending the same gradient the conditions are different. In descending a 25-feet grade (which we have assumed to be just sufficient to keep the train in motion without the aid of steam) we regain in theory the whole increased consumption of power or fuel on the corresponding ascent, but practically only about two-thirds of this amount, the remaining third going out of the chimney or safety valve when the engine is not using steam. But, in the words of Vose's Manual, "if the grade be ten times steeper, we do no more," the additional momentum of the train being simply taken up by the brakes and lost. Accordingly we see that there is a certain inherent disadvantage in a high grade as compared with a lower one, independent of the effect of grades as a limiting agent to the weight of trains. This becomes evident in the following table:

RATE OF GRADE PER MILE.	25	37½	50	75	100	125
Increase in cost of fuel per mile, ascending...........	6 cts.	9 cts.	12 cts.	18 cts.	24 cts.	30 cts.
Saving in cost of fuel per mile, descending................	4 "	4 "	4 "	4 "	4 "	4 "
Net increase in cost of fuel, per mile of ascent and corresponding descent..	2 cts.	5 cts.	8 cts.	14 cts.	20 cts.	26 cts.
Increase per train mile in other expenses (as previously determined), at 4 cts. per 25 feet of rise and fall).......	4 "	6 "	8 "	12 "	16 "	20 "
Total increased cost per train mile.....	6 cts.	11 cts.	16 cts.	26 cts.	36 cts.	46 cts.
Equal to a total increased cost per train mile, *per 25 ft. of rise and fall*, of...	6 "	7½ cts.	8 "	8⅔ "	9 "	9.2 "

Thus we see, by the last line of the above table, that there is a slight increase in the cost of rise and fall on higher grades, but the difference—due entirely to the greater waste of power in descending them—is a refinement of little real importance (except perhaps in one respect, which we shall briefly consider below), and in discussions of the subject this difference has usually been neglected altogether. Thus in *Engineering* (Feb. 5, 1869), we find the general rule laid down that "descending gradients may be considered equivalent in cost of working to a level line," thus balancing the saving of fuel against the wear and tear of road bed and rolling stock, whatever each may be; and in Vose's "Manual for Railroad Engineers" (p. 44) we find a similar statement. But it is evident that as the wear and tear increases with the grade and the saving of fuel is constant, this is not strictly correct, although the hypothesis has the convenient effect of making the cost of rise and fall independent of the rate of grade. As the effect of the rate of grade is shown in the above table to be relatively much less on the higher grades, we may, for the purpose of location estimates, assume an average of 8 cents per train mile as the cost of 25 feet of rise and fall on all grades higher than 40 feet per mile; noting the percentage of difference on higher and lower grades, which we shall determine below.

Expressing this amount, 8 cents per mile per 25 feet, in the form of *the yearly cost per daily train of one foot of rise and fall*, we have, allowing 325 days in the year, and multiplying by two for the round trip,

$$\$0.8 \times 325 \times 2 \div 25 = \$2.08.$$

This amount, divided by the rate of interest on capital, 0.6, 0.7, etc., gives the values given in the first column of Table C, below.†

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†The writer is well aware that this estimate of the cost of rise and fall will seem very small in comparison with some others. Thus, in Vose's "Manual for Railroad Engineers" the estimate of increased cost from a double resistance, for grades of 25 feet or less, is one-sixth, or 16⅔ cents per mile, instead of 8 cents above. Most of this difference is accounted for by the fact that Professor Vose's estimate is based on the Massachusetts Reports, where the cost of fuel is 12 per cent., and by the fact that the whole cost of fuel is considered in the "Manual" as doubled on a grade of double resistance, thus making the increased cost of fuel in ascending 12 cents instead of 6 cents, as by our estimate. There remains, however, a balance of 4⅔ cts. per mile plus the saving in fuel in descending, which we have estimated at 4 cents, as an allowance for wear and tear, for which we have estimated but 4 cents in all. On the higher grades Professor Vose's estimates would exceed those we have given in much greater proportion. The writer can only frankly admit that these differences are

In the case of projected improvements in the alignment of railways already in operation, for which exact statistics of expenses may readily be determined, we may also express the cost of one foot of rise and fall as follows:

The cost per train mile of one foot of rise and fall is \$0.08 ÷ 25 = \$0.0032. Then the yearly cost of operating one foot more or less of rise and fall is

$\frac{0.32}{100}$ or 0.0032 times the average yearly TOTAL EXPENSES per mile of road.

$\frac{0.32}{70}$ or 0.0046 times the average yearly "transportation" or "line" expenses per mile.

$\frac{0.32}{10}$ or 0.032 times the average yearly cost of fuel per mile.

The amounts, or percentages, last given above, multiplied by the average yearly expenditure per mile for the items opposite to it, give the total yearly cost of operating one foot of rise and fall, and divided by the rate of interest on capital, give the capitalized value of saving one foot of rise and fall. We thus obtain the last three columns of Table C.

VALUE OF REDUCING THE RATE OF GRADIENTS ON OTHER THAN RULING GRADES.

We have seen above that, owing solely to a greater economy of fuel in descending on moderate gradients, there is a certain slight inherent disadvantage in a high rate of grade, independent of the effect of the *highest* rate of grade as a limiting agent to the weight of trains. The difference is too slight to be of much real importance, but lest the nature and effect of such difference as there is be misapprehended and exaggerated, we may briefly consider it.

The following table summarizes, in the briefest and most convenient form, the results we desire to reach.

The fourth line of this table gives the percentages by which, if strict correctness is desired, the values given in Table C must be corrected in estimating the cost of rise and fall on different grades. These percentages are given—in round figures— im-

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irreconcileable and express his belief that the estimates here given are sufficiently large for the *direct* effect of gardients as sources of expense, when the entirely distinct question of their effect as limiting agents on the weight of trains is not mixed up with it. It is difficult to resist the tendency, in such estimates as these, to err by *overestimating*, as it is proper to do in nearly all estimates which an engineer is called upon to make, but consideration will show that in this case the errors should all lean to the conservative side.

1. RATE OF GRADE IN FEET PER MILE.	12½	25	37½	50	75	100	125
2. RATE OF GRADE IN FEET PER STATION.	.24	.48	.71	.95	1.42	1.90	2.37
3. Cost, in cents, per train, of 25 feet of rise and fall on each grade (as already determined above)........................	(4.)	6.	7.33	8.	8.67	9.	9.2
4. Percentage which the cost per 25 feet on each grade forms of 8 cents, assumed for the standard of Table C..........	.50	.75	.915	1.00	1.085	1.125	1.15
5. Difference between the percentages of cost on each grade........................	.25	.165	.085	.085	.04	.025	
6. Difference in the rate of grade per station, in feet...........	.24	.23	.24	.47	.48	47	
7. Dividing the first of these two differences by the second, we deduce the value per vertical foot of a reduction of 0.1 PER STATION in the rate of any grade, in the form of a percentage on the value of 1 foot of rise and fall which is given in Table C, as follows........	.104	.072	.036	.018	.008	.005	

mediately below Table C, but they are of importance, as appears to the writer, only as showing the very slight cost of rise and fall on low gradients, 0.5 or less per station, and except in that respect may, for all practical purposes of location, be neglected altogether; the cost of rise and fall on higher gradients being estimated at so much per vertical foot, independent of the rate of grade.

The seventh and last line of the above table shows the value of *reducing* the rate of grade on other than ruling gradients, which are also given, in round figures, at the foot of Table C. They are given less on account of their importance than to definitely illustrate the unimportance of such reduction of minor gradients.

The above table sufficiently explains itself and the method of obtaining these percentages, except that the cost given, in the third line, for 25 feet of rise and fall on a grade of 12½ feet, has not previously been determined. On such a grade steam must be used both in ascending and descending and there can hardly be said to be any increased cost of fuel, all power lost in ascending being saved in descending. At least, such slight loss as there is will be fully covered if we estimate the wear and tear of track and rolling stock at the same rate per 25 feet of rise and fall as on higher gradients (*i. e.*, at 4 cents per train). We thus obtain 4 cents per 25 feet—only half of the cost on a 50 feet gradient—as the cost of rise and fall on a 12½ feet grade.

TABLE C,

SHOWING THE CAPITALIZED VALUE OF SAVING ONE FOOT OF RISE AND FALL ON GRADIENTS OVER 40 FEET PER MILE AND NOT EXCEEDING THE RULING GRADE, ASSUMING A TOTAL COST PER TRAIN MILE OF $1.00.

RATE OF INTEREST ON CAPITAL.	PROJECTED LINES.		RAILWAYS IN OPERATION.	
	For each estimated daily train (round trip) over the line.	For each estimated $1,000 of yearly expenditure per mile.	Multiply the average annual expenditures per mile for either of the following items by the number given below it, opposite the proper rate of interest.	
			All "transportation" or "line" expenses.	Fuel only.
5 per cent.......	$41 60	$64 00	.092	.64
6 " "	34 67	53 33	.076	.53
7 " "	29 71	45 71	.067	.46
8 " "	26 00	40 00	.057	.40
10 " "	20 80	32 00	.046	.32
YEARLY COST of 1 ft. of Rise and Fall	$2.08	$3.20	.0046	.032

REMARKS.—These values are strictly correct only for gradients of about 50 feet per mile. To estimate the cost of rise and fall on other gradients with greater exactness, the values given above should be corrected by the following percentages:

On 12½ feet per mile grades, 50 per cent. less than the above.
" 25 " " " " 25 " " " " " "
" 35 " " " " 10 " " " " " "
" 80 " " " " 10 " " more " " "
" 125 " " " " 15 " " " " " "

VALUE OF REDUCING THE RATE OF MINOR GRADIENTS.

On a rate of grade per station of	A reduction of .1 per station in the rate of grade is worth (per vertical foot)
Less than 0.5..........	10 per cent. of the values given in Table C
0.5 to 0.7.	7 " " " " " " " " "
0.7 " 1.0..........	4 " " " " " " " " "
1.0 " 1.4..........	2 " " " " " " " " "
Greater than 1.4..........	1 " " " " " " " " "

For example, to reduce any ascent of 200 feet from the rate of 0.6 per station to the rate of 0.3 (with a ruling grade of say 0.8 per station) is worth 7 + 10 + 10 = 27 per cent. of the value given in Table C. Then at 6 per cent. the value per daily train would be $34.67 × 200 × 27 per cent. = $1,872.18, or, for an estimated business of 10 trains daily, $18,722.

" EQUATING " FOR RISE AND FALL.

The yearly cost per daily train of 1 additional mile of distance has been previously determined as..................	$273 00
The corresponding cost per daily train of 1 additional foot of distance is....................	$0.0517
The yearly cost per daily train of 1 foot of rise and fall, measured by the same standard, we have determined to be...	$2 08

Then it follows that one mile of distance is equivalent to 131 feet of rise and fall—

$$\left\{\frac{\$273.00}{\$2.08} = 131\right\}$$

and one foot of rise and fall is equivalent to 40 feet of distance—

$$\left\{\frac{\$2.08}{\$0.0517} = 40+\right\}$$

Under the head of curvature, we have already determined 1,120° of curvature to be equivalent to 1 mile of distance. Hence, one foot of rise and fall is also equivalent to 8.5° of curvature—

$$\left\{\frac{1,120^\circ}{131} = 8.5^\circ\right\}$$

These equating formulæ are given mainly for purposes of comparison with others, as, if we may use definite money values instead of them, such rules are as clumsy a contrivance as a process of barter in comparison with a currency.

PRACTICAL EXAMPLES OF ESTIMATING FOR RISE AND FALL.

As a practical example of the application of Table C, we may take the following example from Vose's " Manual for Railroad Engineers" (p. 43).

Let us suppose we have two lines, AB, 100 miles long, and CD, 96 miles long; differing in their gradients as shown in the following table, the sign + signifying an ascending grade in going from A to B or from C to D, and the sign — a descending grade. In the third column is given the total amount of ascent or descent on each grade, and the *sum* of these ascents and descents, divided by 2, gives the total number of feet of rise and fall on each line :

To compare these lines in terms of the cost per daily train,

LINE AB—100 MILES.			LINE CD—96 MILES.		
DISTANCE.	Rate of grade in feet per mile.	No. of feet of rise or fall.	DISTANCE.	Rate of grade in feet per mile.	No. of feet of rise or fall.
30 miles.......	+50	1,500	20 miles.......	+60	1,200
20 "	—20	400	10 "	—20	200
10 "	+60	600	15 "	+30	450
15 "	—15	225	15 "	—15	225
15 "	+20	300	26 "	+30	780
10 "	—40	400	10 "	—50	500
100 miles.......	Total.	3,425	96 miles.......	Total.	3,355

Ruling grade, going from A to B...... .... 60 ft.
Ruling grade, going from B to A................. 40 ft.
No. of feet of rise and fall........... $\frac{3,425}{2} = 1,712.5.$

Ruling grade, going from C to D................. 60 ft.
Ruling grade, going from D to C................. 50 ft.
No. of feet of rise and fall........... $\frac{3,355}{2} = 1,677.5.$

we have (assuming the rate of interest on capital to be 7 per cent.):

In favor of line C D, 35 feet of rise and fall, @ $29.71 per foot	$1,039 85
In favor of line C D, 4 miles distance, @ $3,900 per mile..	15,600 00
Total value of line C D over line A B, per daily train....	$16,639 85

Per contra, we have, in favor of the line A B, a ruling grade 10 feet lower in going from B to A than in going from D to C. The value of this difference, if any, would depend on the relative weight of trains in each direction, and we are not now prepared to estimate it. It might be of much importance, or it might be of none whatever.

"Equating" these same lines, we have:

Difference in rise and fall in favor of CD, 35 feet, = 0.267 miles,

$$\left\{\frac{35}{131} = 0.267\right\}$$

" " measured length " " 4.000 "

Total "equated" difference of length, in favor of C D..4.267 "

Then, 4.267 miles × $3,900 = $16,641.30, as the value per daily train of line C D over line A B, the same as before, barring a slight difference from neglect of decimals.

This example is worked out in the "Manual" with a result precisely the reverse of that we have obtained above. That is to say, the gradients of the two lines are made to show a balance in equated distance of 1.37 miles in favor of A B instead of 0.36 miles in favor of CD. Without going into details, this result is due to the fact that, as appears to the writer, the rules of the "Manual" confuse the question of rise and fall with that of ruling grade, to the destruction of their value as a guide in either case. We may conclusively show this, as it happens, by an illustration which will also serve us as a practical example in considering our next subject.

Let us take the line A B, and instead of the undulating and irregular profile shown in the table above; let us suppose the same amount of ascent and descent to be concentrated entirely at each end of the line on the same ruling gradients. We should thus obtain the following profile:

	Line A B, with revised profile.	
40 miles.	rising 60 feet per mile..............	2,400 feet ascent.
34.38 "	level.	
25.62 "	falling 40 feet per mile	1,025 feet descent.
100.00 miles.	Totals (same as before)	3,425 feet.

"Equating" these two lines according to the rules of the "Manual," we obtain the following singular result:

	Line A B, with the original gradients.	Line A B, with revised profile shown above.
Equated length, going from A to B........	123.15 miles.	129.63 miles.
Equated length, going from B to A........	107.56 "	112.64 "
Mean equated length.	121.14 "	115.35 "

In other words, the difference in gradients is made to appear as equivalent to nearly six miles of distance in favor of the undulating profile, yet the revised profile is, in comparison with the other, an admirable system of gradients, rendering possible a very great economy in operating expenses with any considerable business, and worth many thousands of dollars more than the other for a very moderate business. How much more, we shall endeavor to determine hereafter, in considering the adjustment of gradients.

REDUCTION OF RULING OR MAXIMUM GRADE.

A maximum grade causes an increased expense, which depends for its amount on the elevation attained, like all other gradients. This is practically independent of the rate of ascent, and we have already considered it in the previous chapter, under the head of RISE AND FALL. It is that portion of the expense of gradients which directly and invariably appertains to them, or what we have termed the *inherent* expense of any deviation from a level.

In addition to this the MAXIMUM grade of a line *usually* has the distinct and far more important effect of increasing either the number or the weight of engines (in other words, the ENGINE TONNAGE, as we shall hereafter term this composite quantity) which is required to transact the business of the road, thus increasing the expense of operating the entire line; and a mile or two of heavy grade will thus limit the weight of trains as effectually as 20 miles. It is this effect of gradients which we propose now to consider. In only one case does the maximum grade fail to have this effect, viz., when the curvature is so sharp and the gradients so low that the curves intervene in advance of gradients to limit the weight of trains. This is very rarely the case, but in order that such an effect from curvature may be avoided without needless and wasteful expenditure, the minimum radius permitted should be correctly adjusted to the maximum gradient. This is one of the most important and most neglected subjects connected with the location of railways, and we shall separately consider it before completing this paper. It is often absurdly and arbitrarily decided.

The effect of the highest rate of grade in fixing the engine tonnage is an external or accidental attribute, as we have een under the head of Rise and Fall, which depends solely on the rate of ascent and not at all on the elevation attained; while exactly the reverse is the case with that inherent and universal expense from gradients which has no limiting effect, but results from all ascent and descent, whatever the rate. For example, let us suppose we have a located line 90 miles long with a maximum grade at all points of the line of 40 feet per mile, except two or three miles of 50 feet grade. Now in deciding upon the location of the latter, a very great expenditure per mile may be justifiably incurred to reduce the rate of the

50 feet grade to 40 feet per mile, and in addition thereto a certain amount of expenditure (and a very moderate amount) may be properly incurred to reduce the *length* of the grade, *i. e.*, the height of the summit. Let us now suppose that it is subsequently decided to extend the line 10 miles further, and that on this extension the minimum gradient attainable, by any justifiable expenditure, is 52.8 feet per mile. The proper alignment for the original location is now very different, and the original alignment, if at first judiciously located, will require an entire readjustment. All expenditure to reduce the rate per mile of the 50 feet gradient has now ceased to be justifiable—except an inconsiderable fraction which we have considered under the head of Rise and Fall—and in addition thereto if *anything* can be saved (beyond the aforesaid inconsiderable fraction) by increasing the rate of the 40 feet grade and other minor gradients up to any rate less than the superior limit of 52.8 feet per mile, it should be done. The justifiable expenditure to reduce the height of the summit, however, or to avoid any other rise and fall, remains unaffected. The latter is the *inherent* expense of gradients, the former is external and accidental, and the two are wholly distinct and dissimilar, both in their nature and effect.

When the gradients are such that assistant engines may be economically employed, the effect of gradients and their proper adjustment is somewhat different. We shall consider that question hereafter. For the present, we assume that assistant engines are not intended to be used, but that trains are to be run through without change from one end of the line to the other. If trains are broken up at any point of the line, such distance as they *are* run through without change constitutes in effect a separate line or division, but the breaking up and recombining of trains at frequent intervals form a very expensive and undesirable necessity which is hardly susceptible of exact estimation, but should always be borne in mind. We shall have occasion to refer again to the subject hereafter when we have more data available.

We have been thus particular, in the above remarks, to define the subject we propose to consider because it is one of real difficulty and of undeniable intricacy, if the results finally obtained are to possess any value. It is not difficult to devise a short cut to an estimate. Several such are known to the writer. But the difficulty with them all, so far as the writer's knowledge extends, is that they are either based on incorrect premises or are otherwise easily capable of a *reductio ad absur-*

dum. Hence they will not stand practical tests, and are deservedly consigned to the limbo of forgetfulness in preference for the rule of thumb. And in the great majority of instances it is the thumb of the left hand, for the profound importance of well-adjusted ruling gradients to the financial future of any railway, in comparison with the more showy and striking improvements, such as a short line, flat curves and low summits, is hardly appreciated by many of the locating engineers who *practically* decide the balance between such matters in the field, and, if the seeming egotism may be pardoned, is not thoroughly comprehended and correctly understood in detail by many engineers of long experience and of distinguished ability. As to this fact "their works do testify," as we shall have occasion to see. For some inscrutable eason the principles underlying the proper and economical adjustment of the alignment of railways has not been deemed worthy of that careful and general analysis which is so freely bestowed on the size of a link pin, and, in the haste of actual practice, the ablest engineers do not seem exempt from unmistakable errors such as might be expected only from those of very limited experience. We now refer more especially to our present subject of the proper adjustment of gradients.

It is hoped to make the discussion of this subject clear and easily followed, and to secure final results in tabular form, similar to those heretofore obtained in these papers, of ready and simple application in practice; but it is not hoped or expected to reach this result quite as readily or simply as heretofore. To estimate *correctly* the cost of ruling grades, in a form which will answer the practical requirements of location, we must begin from the foundation, and consider, in some detail, the following points:

1*st.* *The power of engines on various grades;* that is to say, the load which engines can be depended on to haul up any grade under all ordinary circumstances.—In order that our results may be general, we shall determine this in the form of a ratio to the tractive power, and for both gross and net loads.

2*d.* *The percentage of change in the net load resulting from any given increase or decrease in the rate of any grade.*—We shall find this to vary considerably on different grades but to be nearly uniform *per foot* of increase or decrease in the rate of any given grade.

3*d.* *The increase in operating expenses which would result from such a change in the ruling grade as would double the engine tonnage required to move a given business.*—Such a change would be met in practice by an increase both in the number and in the weight of engines; mainly, however, for practical reasons, in the number of engines. We shall therefore estimate the cost of an increase in each separately, and take an average between them.

These problems are merely preliminary to those which follow. After solving them, we shall have all the requisite data for determining,

1st. The following purely abstract quantity, the definition of which, in order to fix it in the memory, the patient reader is requested to read over twice, viz.: *The increased cost* PER TRAIN MILE REQUIRED TO MOVE A FIXED TONNAGE ON ANY GIVEN MAXIMUM GRADE, *resulting from the addition of any number of feet per mile to the same.* In other words, the cost per train of *increasing* the number of trains required, by increasing the maximum grade. This, it is true, is merely an abstraction, but it affords the simplest basis for a ready and *correct* comparison of alternate alignments, if not the only one, and it is well adapted for the important and difficult purpose of striking a just balance between the value of reducing grade, saving distance, curvature, etc., and the readjustment of gradients for the use of assistant engines.

The same values which apply to an increase of maximum grade we shall find to apply also (negatively, of course) to a decrease of grade.

2d. *The value per loaded car of reducing the ruling grade*—a form of estimation less suitable for comparative purposes, but sometimes more convenient when the value of reducing the ruling grade alone is to be estimated, especially in the case of roads already constructed and in operation.

3d. *The proper balance of ruling grades for an unequal traffic in opposite directions.*

4th. *The correct adjustment of the minimum radius of curvature to the rate of the maximum gradients.* The last two subjects form an essential part of any thorough consideration of the subject of gradients, and have been as arbitrarily decided, with as much folly and unreason, and with as serious results to the finances of railway companies, as any others connected with railway location.

5th and lastly. *The effect of a difference in ruling grade on the cost of distance, curvature and rise and fall*—a subject of occasional importance in attempting a just comparison between alternate alignments which differ considerably in the rate of the ruling grades.

THE POWER OF ENGINES AS AFFECTED BY HIGH RULING GRADES.

The *absolute* effect of gradients to increase the load on the engine is constant and easily determined. It is equal to the

$$\frac{\textit{grade in feet per mile}}{5.280} \times \textit{gross weight of engine and train.}$$

It is the *relative* effect, however, which we desire to determine, and this depends, so far as the gross load is concerned, upon a single variable quantity, viz., THE ROLLING FRICTION PER TON ON A LEVEL. We have already determined an *average* value for the rolling friction in considering the subject of rise and fall; but this value would not be a correct one for our present purpose. In addition to this, there is another variable element which we must determine. The true measure of the cost of gradients is their effect upon the *net* or paying load of cars and freight, and not upon the gross load; and the effect upon the *net* load depends upon an additional variable, viz., the RATIO *of the gross weight of the engine and tender to the tractive power of the engine.* This latter variable again is itself the product of two variable elements, viz., THE RATIO OF ADHESION, depending on the condition of the track, and THE RATIO OF THE WEIGHT ON DRIVERS TO THE GROSS WEIGHT OF ENGINE AND TENDER, depending on the pattern of engine.

Having determined the proper values for these three variables, we shall have all the data requisite to construct a general table of the power of engines on different grades which shall be independent of the exact weight of the engine and train. From this table (Table XVII.) we can easily determine the law which governs the effect of different changes of grade.

The Rolling Friction per Ton.—This varies, at slow speeds, from 6 lbs. per ton under favorable conditions to upwards of 12 lbs. per ton in bad weather and on poor track. In the article on Rise and Fall we have assumed 9.3 lbs. as a fair average for all trains at an average speed of 20 miles per hour. For freight trains only at a speed of say 10 miles per hour, the average rolling friction would be much less, say 6 to 8 lbs. per ton.

To estimate the cost of high grades, however, the *average* rolling friction is not a proper standard, as previously stated, and a neglect of this fact has led to great overestimates of the value of reducing high grades. The rolling friction for this purpose should be determined, not from the load which an engine *can* haul under favorable or even average conditions, but from the load which it actually *does* haul, day after day, over the roughest parts of the track and in all but extraordinarily bad weather. For example, we will suppose that an engine setting out for a run over a perfectly level road could haul without difficulty 80 cars at a slow speed, and might haul 90 except on a short section of bad track. The *average* resistance over the whole line would then correspond to a load of say 88 cars, but even 80 cars would be an excessive measure of the capacity of the engine by which to estimate the effect of high grades; for as a matter of every day practice, an engine is always loaded so lightly as to be "well in hand" for such contingencies as a slippery track and a higher speed to make up time at the points of greatest resistance, and the ordinary train over such a line for an engine which might haul 80 cars under favorable conditions would probably be about 60 cars more or less. Hence, the rolling friction corresponding to *that* load is the proper (because it is the actual) measure of the cost of higher grades. It is plain that to exaggerate the load which engines would haul, as a matter of every day practice, *except* for gradients, is to unduly exaggerate the cost of the gradients themselves.

The rolling friction to be assumed (and also the ratio of adhesion) can be most properly determined from the habitual loads hauled by the same engine on different grades, by eliminating the constant effect of gravity. This is a problem of the simplest description, as follows:

Having given the gross loads, L and L', habitually hauled by the same engine up two different grades, g and g', required to determine the rolling friction and also the ratio of adhesion, corresponding thereto.

Let x = the *total* resistance per ton on the lowest grade, g;
d = " *difference in* resistance per ton on grades g and g' (the latter is due to gravity only and is equal to the resistance from gravity on a grade of $(g - g')$. It is given at once in the second column of Table XVII.)

Then

$$L\,x = L'\,(x + d),$$

and

$$x = \frac{L'\,d}{(L - L')}$$

Having determined x, we have

$$\text{Rolling Friction} = x - \begin{cases} \textit{resistance from gravity only on grade } g, \\ \text{(given at once by Table XVII).} \end{cases}$$

To determine the ratio of adhesion we have

$$x \times L = \text{traction of engine},$$

and

$$\frac{\textit{traction}}{\textit{wt. on drivers}} = \text{Ratio of adhesion.}$$

TABLE XV.,

Showing the rolling friction, rate of adhesion, etc., deduced from the average experience of various roads, and from estimates of leading engineers.

NAME OF ROAD.	AUTHORITY.	Where quoted.	Rolling friction.	Ratio of adhes'n	Ratio of tractive power to wt. of eng.	Tons on drivers.	Wt. eng. and tender.	Grades.	Gross loads.	Angle of friction in ft. per mile.
Penna. R. R	A. J. Cassatt, Gen. Supt.	Vose, p. 515	10.57	¼	1 to 9.5	26.5	62.75	10 & 96	922 & 282	28
"	" " " "	" " "	8.73	1-4.6	1 to 10.8	"	"	10 & 52.8	922 & 402	23
"	H. J. Lombaert, Vice-Pres.	" " "	9.1	1-4.75	1 to 11.3	"	"	10 & 52.8	882 & 382	24
Phila. & Read'g.	Steele	" " 514	9.5	1-5	1 to 12.	18.	43.5	Lev. & 100	768 & 154	25
Lehigh Valley	(Av'g's of several reports.)	" " 403	7.49	1-5.1	1 to 8.9	40.	69.	21 & 133	1,012 & 270	20
Erie Railway	Z. Colburn's experiments.	" " 508	5.07	1-3.08	1 to 6.6	20.	43.	6 & 60	1,765 & 464	13
"	Present daily experience	....	11.5	1-5.1	1 to 9.52	37.5	70.	6 & 60	1,070 & 430	30
Va. Cent. R. R.	Charles Ellet	Vose, p. 61	10.	1-6.2	1 to 6.2	27.5	27.5	....	....	26
	Estimates of Engineers.									
P. & Ogd. R. R.	B. H. Latrobe, Cons. Eng.	Vose, p. 510	12.	1-7	1 to 10.8	32.	65.	116 & 200	214 & 136	32
U. P. R. R.	Col. Seymour, Chief Eng.	U. P. R. R. Rep.	6.	....	....	....	....	....	....	16
Shen'h Val. R. R.	Herman Haupt	Van N., May, '71.	9.16	....	1 to 11.4	....	....	30 & 53	541 & 380	24
Assumed as a standard, for purposes of this paper		....	10.	1-5	1 to 10.	....	....	....	....	26

Remarks.—*Erie Railway.*—The first line given above is based on the exceptionally favorable results of Mr. Zerah Colburn's widely-quoted experiments, made many years ago. The second line is based on the present daily practice of the road. With a 70-ton engine (including tender, loaded) the usual train on the Susquehanna Division going east is from 45 to 50 or more cars (taken as 50 cars or 1,000 tons), ruling grade 6 feet per mile. On the Eastern Division, for the same engine, the usual load, up 60-feet grade, is 18 cars. On the Susquehanna Division, however, the curvature intervenes in advance of gradients to limit the weight of trains to some extent; how much the writer has no data for determining, and except for that fact the rolling friction would doubtless be lower, say 9 or 10 lbs. per ton.

Virginia Central Railroad.—The results given are for very steep grades (296 feet per mile) operated with tank engines, consequently the ratio of tractive power to weight of engine and tender far exceeds any other in the table, except Zerah Colburn's, above referred to.

Pennsylvania Railroad.—The statistics on which the above results are based were given to Mr. Herman Haupt for this especial purpose, as a basis for his calculations for the gradients of the Shenandoah Valley Extension Railroad.

Union Pacific Railroad.—Col. Seymour's estimate was confessedly based, in his reports, on the exceptional results of Mr. Zerah Colburn on the Erie Railway.

Lehigh Valley Railroad.—Comparison by the formula of a mass of different returns gave very irregular results, indicating that the facts had not been very carefully observed. Moreover, the statistics given were mainly as to what special engines *had* done and not what they habitually do. A lower rolling friction therefor was to be expected.

TABLE XVI.,

Showing the Ratio of Weight in Drivers to Total weight of Engine and Tender for Various Patterns of Engines.

STYLE OF ENGINE.	Weight of Engine. (Tons of 2,000 lbs.)			Weight of Tender. (Tons of 2,000 lbs.)			Grand	Ratio of weight on drivers to weight of engine and tender.	
	On drivers.	On truck.	Total.	Tender empty.	Load.	Total.	total.	Tender loaded.	Tender empty.
Baldwin "Standard American"	21.	11.5	32.5	10.	11.	21.	53.5	0.393	0.494
Penna R. R. Standard Passenger	19.5	12.05	31.55	9.87	13.5	23.37	55.12	0.353	0.470
" " " Freight	24.	10.25	34.25	9.87	13.5	23.37	57.62	0.418	0.542
"Mogul" Engine, 2-wheel truck	30.5	4.5	35.	9.5	10.5	20.	55.	0.554	0.686
" " 4 " "	29.	9.5	38.5	10.	12.	22.	60.5	0.480	0.600
"Consolidation" Engine, 2-wheel truck	40.	5.	45.	11.	13.	24	69.	0.580	0.726
"Mogul" Erie Railway 2 " "	37.5	7.	44.5	....	....	26.7	71.2	0.526	....
" P. B. & W. R. R., 4-wheel truck	30.	10.	40.	....	....	20.	60.	0.500	....
Assumed as a standard for the purposes of this paper								0.5	

By substituting in the latter formula the *gross weight of engine and tender* for the weight on drivers, we determine at once the ratio to it of the tractive power.

By this formula and with data from various sources as shown, Table XV., below, was computed, from which we may assume an average rolling friction of about 10 lbs. per ton as the proper one by which to measure the effect of ruling gradients. A nearer approach to the facts might perhaps be about 9½ lbs., but it is deemed proper to carefully avoid an over-estimate, as heretofore. Mr. Benj. H. Latrobe, in adjusting the very high gradients of the Portland & Ogdensburg Railroad, considered a rolling friction of 12 lbs. per ton as the lowest rolling friction which could properly be assumed, and this is doubtless no higher than is occasionally encountered; but, with deference to Mr. Latrobe's high authority, it appears to be higher than the rolling friction which is practically assumed in fixing the habitual load of engines, and therefore excessive. *Occasionally* on all railways trains will get stalled which are able to overcome a rolling friction of 10 lbs. per ton, but if experience has shown it to be uneconomical to limit the weight of trains to a higher rolling friction *after* construction, it is bad practice for the engineer to assume a higher standard for the adjustment of his gradients—although it is far worse practice to assume a lower one. A distinguished example of the latter error is an estimate made for the Union Pacific Railroad by Col. Silas Seymour, the Consulting Engineer of the road, to determine the advantage of adopting a longer line and lower grade near Omaha. As a basis for this estimate, Colonel Seymour assumed a rolling friction of only 6 lbs. per ton, confessedly based on Colburn's Experiments on the Erie Railway, which were for the purpose of determining the *maximum* power of engines under very favorable conditions. The every day practice of the Erie Railway would have given nearly double this rolling friction. Under this assumption, the apparent value of the longer line and lower grade is just double what would be given by the assumption deemed proper by Mr. Latrobe. It is perhaps an unkind suggestion that Colonel Seymour was at that time engaged in proving to a board of government engineers that the longer line was greatly to the advantage of the company *independent* of the government subsidy of $16,000 per mile. We shall hereafter endeavor to determine the true difference in value of these alternate alignments, on the basis of Colonel Seymour's data.

The Ratio of Adhesion (i. e., the ratio of the tractive power of the engine to the weight on the drivers).—This varies from 1-3 to 1-7. The *maximum* adhesion, about 36-100, is shown by Colburn's experiments on the Erie Railway, before referred to. Experiments by Mr. Reuben Wells, the able Master Mechanic of the Jeffersonville, Madison & Indianapolis Railroad, on the Madison inclined plane, indicate that an adhesion of about $\frac{1}{4}$ may be relied on under favorable circumstances, as shown in the following extract from Mr. Wells' report:

> "The engine is what is called a tank engine, with cylinders $20\frac{1}{8}\times24$ inches. The wheels are all drivers, and consist of five pair, 44 inches in diameter; tires, steel. The inclined plane is 6,940 feet in length, and the track is inclined 1 in $16\frac{1}{2}=320$ feet per mile. A train of eight loaded cars was taken up this grade as follows:
>
> "Weight of engine, 54 tons; weight of train, 154 tons; total, 208 tons; speed at starting on the incline, 2 miles per hour; steam pressure, 140 lbs.
>
> "Average speed, 6.06 miles per hour; fuel consumed, 0.56 cord of wood; time consumed in overcoming the elevation of 420 feet, 13 minutes; pressure at top of incline, 130 lbs.
>
> "The power requisite to overcome the force of gravity on this incline would be 1-16.5 the total weight of the train, or 25,212 pounds, and if we add eight pounds per ton for rolling and journal friction, we have then a total of 26,876 pounds. To overcome this, an effective pressure of 122 pounds per square inch is required, which is equivalent to 434 horse-power, or 14,324,908 foot-pounds per minute. The weight on the drivers available for adhesion on the incline is $1\text{-}16\frac{1}{2}$ less than the weight on a level track, and in this case would be 101,455 pounds.
>
> "Leaving off the power absorbed in rolling and journal friction of the engine, the adhesion of the drivers to the rails required to take this engine and train up the grade would be 25,286 pounds, or $24\frac{3}{4}$ per cent. of their total weight on the rails. The rails were dry and there was no indication of slipping at any time, and no sand was used; therefore we may conclude that the adhesion of a steel tire to a dry iron rail, at slow speeds, and on a straight track, is, in round numbers, at least 25 per cent. of the weight on the rail." ("Report on Locomotive Tests" to Master Mechanics' Association, *Railroad Gazette*, May 26, 1876.)

On the other hand, it is very frequently the case that an adhesion as low as 1-7 cannot be realized in bad weather, and in the grass-hopper region, when the forage is good and the grass-hoppers in good condition, it would doubtless fall very nearly to the ultimate limit of $\frac{1}{\infty}$.

Coming in between these extremes, we find, as might be expected, by consulting Table XV., that practical experience has shown it to be most advantageous and economical to adapt the habitual loads to an average adhesion of about 1-5. We shall *therefore* adopt it as the standard for this paper, and not because it measures the actual ratio of adhesion, which doubtless is usually somewhat higher and occasionally somewhat lower. In the estimate for the Portland & Ogdensburg Railroad, before referred to, Mr. Latrobe assumed 1-7 as the standard for the adjustment of gradients, but the same considerations are applicable to such an assumption as those with respect to the rolling friction assumed in the same estimate, remarked upon above. The practical effect is to adapt the unchangeable gradients to an assumed standard which is highly exceptional, and different from that which the ordinary daily practice of railways has shown to be advisable and economical. The less the ratio of adhesion, the less the *comparative* effect of gradients, and hence the less their cost. Hence, to adopt so low a standard as 1-7 is to unduly depreciate their cost. For the purpose, however, of adjusting gradients for an unequal traffic, which was the purpose of Mr. Latrobe's estimate, the ratio of adhesion assumed makes far less difference, as we shall see. In fact, Mr. Latrobe's estimate, having been made for an engine having all its weight on the drivers, agrees almost exactly on the higher grades with those we shall deduce, with our different premises, for the more common patterns of engines; after correcting some obvious numerical errors into which—singularly enough—that distinguished Engineer has fallen, and which—still more singularly—seem to have escaped detection during the construction of the road, which has accordingly been reduced, as we shall see, to a grade 15 feet per mile lower, going east, than it was Mr. Latrobe's evident *intention* to recommend.

Ratio of the Weight on the Drivers to the gross weight of the Engine and tender.—This is a pure question of fact, data for which are given in Table XVI. below for different patterns of engines. Table XVI. also gives the statistics of actual weight, but with these we shall have nothing to do, dealing only with ratios. The smaller this ratio the greater is the cost of high gradients, since the dead weight of the engine—which must be hauled, but does not help to increase the tractive power—is then greater, and hence the *net* load—from which a fixed reduction must be made if the gradient is increased—is so much the less. Therefore, in order not to *overestimate* the cost of gradients, we should not adopt too small a value for this ratio. The "Mogul" pattern in various forms is coming more and more into use, and an estimate of 0.5 for this ratio, for that pattern, would seem by Table XVI. a fair and sufficiently large average. For what is known as the "Standard American" pattern, as shown in the Baldwin and Pennsylvania Railroad standard passenger engine, this estimate is too large, and about 0.4 or 0.45 would be an average. On the other hand, for the rarely used "Consolidation" pattern (and still more for all tank engines), it is too small and should be 0.6 to 0.7. But except in the latter case it is large enough at least and errs if at all on the conservative side. We may add that the effect of variations in this ratio and the ratio of adhesion is very small, comparatively speaking, on gradients of less than 80 or 100 feet per mile. As the grade is increased much beyond that, they become rapidly more important.

By combining these two ratios, we determine the following compound ratio, which is the one we really require, viz.:

The ratio of the tractive power to the total weight of the engine and tender.—The ratio of adhesion being 1-5, and the weight available for adhesion being 0.5, or ½ of the gross weight of engine and tender, we have 1-5 × ½ or 1-10 of the gross weight as the tractive power of the engine, or, in other words, the weight of the engine is 10 times the traction. This corresponds closely with the observed facts on various railways, as directly determined by the formula already given and shown in Table XV. For the "standard American" engine we should have $4\text{-}10 \times 1\text{-}5 = \frac{1}{12.5}$, or $\frac{45}{100} \times \frac{1}{5} = \frac{1}{11.1}$, *i. e.*, the weight of the engine is from 11 to 12½ times the traction, and on the other hand for the "Consolidation" or tank engine we should find the weight to be only about 8 times the traction, but in the latter case if the ratio of adhesion be taken as only 1-7, we shall find the ratio of the gross weight to the traction to be about 10, the same as for the "Mogul" engine with 1-5 adhesion.

We have now all the data required to construct the following table (Table XVII.), which will enable us to solve several problems in respect to gradients in a general form, independent of the exact weight of the engine and train and even to a considerable extent of the pattern of engine and ratio of adhesion, since, as already stated, we shall see that their effect is comparatively small on ordinary gradients. Table XVII. will form the basis of the remainder of this paper, and is given in full for the convenience of the reader for checking and other purposes, although an abridgement might possibly serve our immediate purpose.

TABLE XVII.

Showing, for any grade, the ratio of the customary gross and net load of an engine to the tractive power; or, the load in tons per ton of traction. Also, the resistance from gravity only and the total resistance in lbs. per ton of 2,000 lbs. According to the average daily experience of the the Pennsylvania, the Philadelphia & Reading, the Erie and other railways, shown in Table XV.

Grade in feet per mile.	Resistance in lbs. per ton.		Ratio of load to tractive power.	
	From gravity only.	Total resistance.	Gross load.	Net load.
Level............	0 0	10.00	200.00	190 0
1..............	0.38	10.38	192.68	182.7
2..............	0.76	10.76	185.86	175.9
3..............	1.14	11.14	179.50	169.5
4..............	1 52	11.52	173.67	163.7
5..............	1.90	11.90	168.12	158.1
6..............	2.27	12.27	162.9	152.9
7........... ...	2.65	12.65	158.04	148 0
8..............	3.03	13.03	153.45	143.5
9..............	3.41	13.41	149.12	139.1
10..............	3.79	13.79	145.10	135.1
11..............	4.17	14.17	141.17	131.2
12..............	4.55	14.55	137.50	127.5
13..............	4.93	14.93	134 00	124.0
14..............	5.30	15.30	130.7	120.7
15..............	5.68	15.68	127.5	117.5
16..............	6.06	16.06	124.5	114.5
17..............	6.44	16.44	121.6	111.6
18..............	6.82	16.82	118.9	108.9
19..............	7.20	17.20	116.3	106.3
20..............	7 58	17.58	113.8	103.8
21..............	7.96	17.96	111.4	101.4
22..............	8.33	18 33	101.1	99.1
23..............	8.71	18.71	106.9	96.9
24..............	9.09	19.09	104.8	94.8
25..............	9.47	19.47	102.7	92.7
26..............	9.85	19.85	100.8	90.8
27..............	10.23	20.23	98.9	88.9
28..............	10.61	20.61	97.0	87.0
29.....	10.97	20.97	95.3	85.3
30..............	11.36	21.36	93.6	83.6
31..............	11.74	21.74	92.00	82.0
32..............	12.12	22.12	90 43	80.4
33..............	12.50	22.50	88.90	78.9
34..............	12.88	22.88	87.41	77.4
35..............	13.26	23.26	86.00	76.0
36..............	13.64	23.64	84.60	74.6
37..............	14.02	24.02	83.26	73.3
38..............	14.40	24.40	81.96	72.0
39..............	14.78	24.78	80.71	70.7
40..............	15.15	25.15	79.50	69.5
41..............	15.53	25.53	78.31	68 3
42..............	15.91	25.91	77.79	67.8
43..............	16.29	26.29	76.09	66.1
44..............	16.67	26.67	75 02	65.0
45..............	17.05	27.05	73.96	64.0
46..............	17.42	27.42	72.93	62.9
47..............	17.80	27.80	71.93	61.9

Grade in feet per mile.	Resistance in lbs. per ton.		Ratio of load to tractive power.	
	From gravity only.	Total resistance.	Gross load.	Net load.
48	18.18	28.18	70.96	61.0
49	18.56	28.56	70.02	60 0
50	18.94	28.94	69.11	59.1
51	19.32	29.32	68.21	58.2
52	19.70	29.70	67.34	57.3
53	20.08	30.08	66.49	56.5
54	20.46	30.46	65.66	55.7
55	20.83	30.83	64.87	54.9
56	21.21	31.21	64.08	51.1
57	21.59	31.59	63.31	53.3
58	21.97	31.97	62.56	52.6
59	22.35	32.35	61.83	51.8
60	22.73	32.73	61.10	51.1
61	23.11	33.11	60.41	50.4
62	23.49	33.49	59.73	49.7
63	23.87	33.87	59.06	49.1
64	24.24	34.24	58.39	48.4
65	24.62	34.62	57.77	47.8
66	25.00	35.00	57.14	47.1
67	25.38	35.38	56.50	46.5
68	25.76	35.76	55.94	45.9
69	26.14	36.14	55.34	45.3
70	26.52	36.52	54.78	44.8
71	26.90	36.90	54.24	44.2
72	27.27	37.27	53.66	43.7
73	27.65	37.65	53.11	43.1
74	28 03	38.03	52.59	42.6
75	28.41	38.41	52.07	42.1
76	28.79	38.79	51.56	41.6
77	29.17	39.17	51.06	41.1
78	29.55	39.55	50 57	40.6
79	29.93	39.93	50.10	40.1
80	30.30	40 30	49.62	39.6
81	30.68	40 68	49.16	39.2
82	31.06	41.06	48.71	38.7
83	31.44	41.44	48.26	38.3
84	31.82	41.82	47.82	37.8
85	32 20	42.20	47.40	37.4
86	32.58	42.58	46.98	37.0
87	32.96	42.96	46.56	36.6
88	33.33	43.33	46.16	36 2
89	33.71	43.71	45.76	35.8
90	34.09	44.09	45.36	35.4
91	34.47	44.47	44.98	35.0
92	34.85	44.85	44.60	34.6
93	35.23	45.23	44.22	34.2
94	35.61	45.61	43.86	33.9
95	35.97	45.97	43.49	33.5
96	36.36	46.36	43.13	33.1
97	36.74	46.74	42.79	32.8
98	37.12	47.12	42.44	32.4
99	37.50	47.50	42.10	32.1
100	37.88	47.88	41.78	31.8
102	38.64	48.64	41.11	31.1
104	39.40	49 40	40.49	30.5
106	40.15	50.15	39.88	29.9

Grade in feet per mile.	Resistance in lbs. per ton.		Ratio of load to tractive power.	
	From gravity only.	Total resistance.	Gross load.	Net load.
108	40.91	50.91	39.28	29.3
110	41.67	51.67	38.71	28.7
112	42.42	52.42	38.15	28.2
114	43.18	53.18	37.61	27.6
116	43.94	53.94	37.08	27.1
118	44.70	54.70	36.56	26.6
120	45.45	55.45	36.07	26.1
122	46.21	56.21	35.58	25.6
124	46.97	56.97	35.11	25.1
126	47.73	57.73	34.64	24.6
128	48.49	58.49	34.20	24.2
130	49.24	59.24	33.76	23.8
132	50.00	60.00	33.35	23.4
134	50.76	60.76	32.92	22.9
136	51.52	61.52	32.52	22.5
138	52.27	62.27	32.12	22.1
140	53.03	63.03	31.73	21.7
145	54.92	64.92	30.80	20.8
150	56.82	66.82	29.93	19.9
155	58.71	68.71	29.11	19.1
160	60.61	70.61	28.33	18.3
165	62.50	72.50	27.59	17.6
170	64.40	74.40	26.88	16.9
175	66.29	76.23	26.21	16.2
180	68.19	78.19	25.58	15.6
185	70.08	80.08	24.98	15.0
190	71.97	81.97	24.40	14.4
195	73.87	83.87	23.85	13.9
200	75.76	85.76	23.32	13.3
210	79.55	89.55	22.34	12.3
220	83.33	93.33	21.42	11.4
230	87.12	97.12	20.60	10.6
240	90.91	100.91	19.82	9.8
250	94.70	104.70	19.10	9.1
275	104.17	114.17	17.52	7.5
300	113.64	123.64	16.18	6.2
325	123.11	133.11	15.04	5.0
350	132.59	142.59	14.03	4.0
375	142.06	152.06	13.15	3.1
400	151.52	161.52	12.38	2.4
425	161.00	171.00	11.70	1.7
450	170.46	180.46	11.08	1.1
500	189.40	199.40	10.03	0.0

REMARK.—The above table is based upon a rolling friction of 10 lbs. per ton, adhesion 1-5, and ratio of weight on drivers to gross weight of engine and tender 0.5. Corresponding ratio of the tractive power or adhesion to gross weight of engine, 1-10.

The table can be tested by multiplying any known load which is habitually hauled by an engine up given ruling grades, by the tractive power, or 1-5 of the weight on the drivers.

The second column of Table XVII. gives the resistance of gravity on each grade per ton of 2,000 lbs., which is easily determined by the formula already given. The third column gives the total resistance per ton on each grade by adding 10 lbs. rolling friction to the second column. Then, to determine the fourth column, the total resistance in pounds per ton on each grade, divided into 2,000, will give the *ratio* of the gross load to the traction, whatever the size and power of the engine. If the total resistance per ton be only 10 lbs., as on a level, we have $\frac{2,000}{10} = 200$, *i. e.*, the gross load is 200 times the tractive power of the engine. If the total resistance per ton be 37.88 lbs., as on a 100 feet grade, the gross load will be only $\frac{2,000}{37.88} = 41.78$ times the tractive power of the engine.

To determine the *net* load per ton of traction, which is given in the fifth column, we have only to subtract 10 from the gross load in the fourth column; inasmuch as we have already estimated the gross weight of the average freight engine to be ten times the tractive power. We have thus determined the *ratio* of the net load to the tractive power on any grade independent of the weight of the engine or train. Of this column we shall make frequent use.

We are now prepared to determine the law which governs the effect of an increase or decrease in the rate of various grades, which we must postpone to the next number.

NOTE ON THE WASTAGE OF FUEL FROM RADIATION.

In estimating the cost of curvature and rise and fall, we have estimated the wastage from this source as equal to 10 per cent. of the total cost of fuel. The substantial correctness of this estimate is confirmed by some experiments of Mr. Reuben Wells, Master Mechanic of the Jeffersonville, Madison & Indianapolis Railroad, as given in the "Report on Locomotive Tests" to the Master Mechanics' Association. (Published in the *Railroad Gazette*, May 26, 1876). We quote Mr. Wells' own words:

> "On making a test, which was continued for 12 hours, it was found that it required 25 pounds of coal per hour to keep up a steam pressure of 80 pounds per inch, in the boiler of engine No. 40, when it was clean and in good order and perfectly tight; the boiler had been lately covered with pine lagging and Russia iron jacket, the dampers to the ash-pan were kept closed, and no steam was allowed to escape or leak out, nor was the engine moved during the 12 hours referred to, nor was there any water put into the boiler during that time, and at the end of the test but little difference in the water level could be noticed from that at the beginning. From this it would seem that 25 pounds of coal per hour is required to make good the heat lost by radiation alone, from a boiler of this size, containing

8,200 lbs. of water, under the conditions stated above. At the time of the test the engine stood on a side track, and the temperature of the atmosphere averaged 50 degrees. There was no wind. The test was made March 14.

"At another time, the same month, a four-wheel switching engine weighing 16 tons was kept under steam for 10 consecutive hours, at an average pressure of 80 pounds. No steam was allowed to blow off, the dampers to ash-pan were kept closed, but during the time the engine was run one quarter of a mile to 'pump up,' in order to make good the loss of water from the escape of steam through slight leakage at the throttle and safety valves. In this case the consumption of coal was 32 pounds per hour."

By referring to the "Monthly Locomotive Returns" published in the *Railroad Gazette*, we find that the average consumption of coal per mile run on the Jeffersonville, Madison & Indianapolis Railroad is something under 45 lbs., and this is not far from the general average of all the reports. At an average speed of 20 miles per hour this would amount to about 900 lbs. per mile. Then, 25-900 and 32-900 = from 2.8 to 3.5 per cent. of the total consumption, as the wastage of fuel from radiation *when an engine is in perfect order, wholly protected from wind, and using no steam in the cylinders.* The most moderate estimate would be that the radiation would reach three or four times this amount for an engine in average condition, while using steam and in rapid motion.

THE PERCENTAGE OF CHANGE IN THE NET LOAD RESULTING FROM ANY GIVEN CHANGE IN THE RATE OF ANY GRADE.

We have already determined premises for this purpose in Table XVII., given in the previous paper. The fifth column of that table shows, for any grade, the ratio of the net load to the adhesive or tractive power of the ordinary "Mogul" freight engine; or, as we may express it in another way, the net load in tons per ton of traction, or per five tons on the drivers. From this column we can readily determine the effect on the net load of any changes of grade, as follows:

We see by the fifth column that one ton of tractive power will haul 190 tons of net load on a level, and only 69.5 tons on a 40-feet grade. It evidently follows that the engine tonnage required for a given business, with a 40-feet ruling grade, will be

$$\frac{190.}{69.5} = 2.73$$

times that which would be necessary on a level grade; that is to say, it will be increased 173 per cent. In the same way, if we wish to determine the effect of various changes in a 60-feet grade have :

For an *increase* in rate of grade of	*I. e.*, from 60 ft. per mile to	Formula for *increase* in engine tonnage: with data from Tab. XVII.	Equal to a total increase of	Or, to an *average increase per ft.* of
10 feet per mile.	70 ft. per mile.	$\frac{51.1}{48.8} = 1.14$	14 per cent.	1.4 per cent.
20 " "	80 " "	$\frac{51.1}{39.6} = 1.30$	30 "	1.5 "
40 " "	100 " "	$\frac{51.1}{31.8} = 1.61$	61 "	1.525 "
For a *decrease* in rate of grade of	*I. e*, from 60 ft. per mile to	Formula for *decrease* in engine tonnage: with data from Tab. XVII.	Equal to a total decrease of	Or, to an *average decrease per ft.* of
10 ft. per mile.	50 ft. per mile.	$\frac{51.1}{59.1} = 0.86$	14 per cent.	1.4 per cent.
20 " "	40 " "	$\frac{51.1}{69.5} = 0.74$	26 "	1.3 "
40 " "	20 " "	$\frac{51.1}{103.8} = 0.49$	51 "	1.225 "

In this manner we may make out the following little table for different grades (Table XVIII.), which illustrates better than any formula the law of the change in the motive power required which results from any given change in any grade. An algebraic investigation and formula, showing the facts with the same correctness, would be so intricate as to be incomprehensible.

By examining Table XVIII. we find evidence of two facts :

First. *When the rate of any given ruling grade is increased or decreased, the corresponding percentage of increase or decrease in the engine tonnage required is very nearly uniform per foot, whatever the increase or decrease in rate*, slightly increasing, however, as the increase is greater and decreasing as the decrease is greater. For example, if a 30 feet ruling grade be increased to 40 feet per mile, the increase in engine tonnage required is 2.0 per cent. per foot ; but if it be increased to 70 feet

TABLE XVIII.

Showing the effect upon the engine tonnage required for a given business of various changes in various ruling grades.

Rate of ruling grade, in feet per mile.	Increase per cent. in engine tonnage resulting from an increase in the rate per mile of the ruling grade of—				Decrease per cent. in engine tonnage resulting from a decrease in the rate per mile of the ruling grade of—				Percentage *per foot* given in Table XIX.
	1 ft.	10 ft.	20 ft.	40 ft.	1 ft.	10 ft.	20 ft.	40 ft.	
Level.	4.0	40	82	173	......	......	......	......	4.0
30	2.0	20	40	86	2.0	20	39	......	2·0
60	1.4	14	30	61	1.4	14	26	51	1.4
90	1.2	12	23	49	1.2	11	21	40	1.2
120	1.	10	20	42	1.	10	18	33	1.0
150	0.9	9	18	38	0.9	9	17	31	0.9

TABLE D.

SHOWING THE PERCENTAGE OF INCREASE (OR DECREASE) IN THE ENGINE TONNAGE, PER FOOT ADDED TO (OR SUBTRACTED FROM) THE GRADE, WHICH RESULTS FROM A CHANGE IN THE RATE OF ANY GRADE.

Rate of maximum grade, in ft. per mile.	Per ct. of change in engine tonnage, per ft. of change in rate.	Rate of maximum grade, in ft. per mile.	Per ct. of change in engine tonnage per ft. of change in rate.
Level.	4.0	70	1.4
5	3.4	80	1.2
10	3.1	90	1.2
15	2.7	100	1.1
20	2.4	110	1.1
25	2.2	120	1.0
30	2.0	130	1.0
40	1.7	140	0.9
50	1.5	150	0.9
60	1.4	over 150	0.8

REMARK.—This table is practically correct for any change in ruling grade, and also for any probable pattern of engine, ratio of adhesion and rolling friction. The following are the corrections for strict exactness:

For VERY CONSIDERABLE *changes in the rate of grade.*

For a change in rate of grade of	The per centage above should be increased about
40 feet per mile.	8 per cent.
50 " " "	10 " "
60 " " "	12 " "

For a different pattern of engine (*or ratio of adhesion*):

For a tank or "Fairlie" engine (or any engine weighing only 5 times its adhesion or tractive power) *subtract* 0.3 from each percentage.

For a "Consolidation" engine (or any engine weighing 8 times its tractive power) *subtract* 0.1 from each percentage.

For an "American standard" engine (or any engine weighing 12 times its tractive power) *add* 0.1 to each percentage.

For a different rolling friction:

Add to the per centage given above for a grade of	If rolling friction is assumed to be 8 lbs.	If rolling friction is assumed to be 12 lbs.
Level	1.0	—0.7
20 feet	0.3	—0.2
60 "	0.1	—0.1
100 "	0.0	—0.05

per mile, the increase per foot is 2.15 per cent., or about 8 per cent. (.15÷2.0) more per foot than for the smaller increase.

Second. *The* AMOUNT *of this percentage of increase or decrease in the engine tonnage required varies considerably with each grade, being nearly five times as much on a level as on a 150 feet grade.*

These two facts being definitely ascertained, we have, in order to determine finally the effect of any change of grade upon the engine tonnage required, simply to compute the average percentage per foot for a moderate change of grade, say 10 feet, and assume it to be constant for any increase or decrease in that grade however great, or at least provided it do not exceed 50 or 60 feet per mile. The percentage of error which results from so doing, as we may note without further demonstration than above, is about 10 per cent. for a change of ruling grade as great as 50 feet per mile and varies very nearly in proportion with the extent of the change, being 2 per cent. for a change of 10 feet per mile, 8 per cent. for a change of 40 feet, 12 per cent. for a change of 60 feet, etc. It is too small to be of any practical importance whatever for changes of 50 feet per mile or less, especially as it has the safe tendency of diminishing the apparent value of reducing the grade.

Table D, on preceding page, contains these percentages, for grades varying by a small amount; given in round figures and without that assumed precision which, in the writer's opinion, mars so many discussions of essentially uncertain problems. In order to show the substantial correctness of these percentages, under any reasonable variation in the premises assumed, we also give below Table D statistics showing the maximum effect of any such differences. These may be determined in precisely the same manner as the body of the table, but it would lead us too far to do so at length in the present paper.

We now proceed to our third preliminary problem, viz.: the increase in operating expenses from a change in ruling grade which doubles the engine tonnage required; this being equivalent to determining what proportion of the operating expenses varies directly with the engine tonnage, the car tonnage remaining constant. This amount, multiplied by the *percentage* of increase in engine tonnage per foot of increase in the rate of any grade (given in Table D), will give the cost per foot of such change of rate.

The increase in engine tonnage, as before stated, may be either in the number or the weight of engines; usually somewhat in both but mainly in the former. We shall therefore estimate for each and take an average between them; cautioning the reader again, however, that the money values which we use throughout this paper are not to be taken as definite fixed sums, which, if they do not happen to agree with what seems a proper estimate for any particular road, therefore destroy the value of the estimates of this paper. They are such only when the cost of a train mile is in fact $1.00, as by our standard. In other cases, they are to be regarded as mere *tokens* or *ratios*, based upon the singular constancy of ratio between the direct operating expenses which holds substantially true under the most diverse circumstances, as pointed out in the first paper of this series;—but when these ratios or approximate values are multiplied by the *actual* cost of a train mile they give a close approach to absolute values for any and all roads, although one may run its trains for half the cost per train mile of another.

The Cost of a Double Number of Engines for the Same Business.—The cost of *fuel* would be increased in direct proportion to the number of engines, or by 100 per cent., except that—if the number of engines has been increased solely to overcome an increased resistance on the maximum grade—on the lighter grades of the line, or say for two-thirds of the whole distance, an engine would be only half loaded, and consequently should save nearly half of that portion of the cost of fuel (60 per cent. of the ordinary average consumption) which we have seen, under the head of Curvature and Rise and Fall, to vary directly with the momentary demand for power. Allowing for this exception we should have a net increase of something over 80 per cent. in the cost of fuel (100 per cent. — $\frac{2}{3}$ of $\frac{1}{2}$ of 60 per cent.), but as the rolling friction is probably somewhat higher *per ton* with short trains (as to which see "Note on Rolling Friction," p. 433), we may assume the increase in cost of fuel to be 90 per cent., or 9 cents. The cost of *oil waste and water*, *engine repairs*, *and train wages*, we may assume to be increased by 90 per cent. It should be 100 per cent., except that statistics clearly show that these expenses do not increase quite as rapidly as the train mileage. The cost of *maintenance of cars* would not be affected at all.

Of the expenses for *maintenance of way*, we may assume that the cost of rails (7 cents), of adjusting track (6 cents), and of maintaining the ties and road-bed (7 cents), or 20 cents in all, will vary very nearly with the engine mileage, even if the number of cars be constant. Such excess as there may be in this estimate will be made up by an increase in the items of switches, frogs and sidings (3 cents), and bridges and buildings (4 cents). Station and general expenses will remain practically unaffected.

The cost of a double weight of engines for the same net load is a highly uncertain problem, for which we cannot pretend to reach more than a rude approximation. The cost of *fuel* will undoubtedly be less with a single heavy engine, per car or other unit of power, than with two engines of half the size and power, probably by as much as 15 to 25 per cent. at least, which would give us say 50 per cent. increase in the cost of fuel (1.90 — 15 to 25 per cent. = 1.61 to 1.42, or 61 to 42 per cent. increase). The cost of *oil waste and water* would be perhaps 50 per cent. greater also. As to the difference in the cost of *engine repairs*, the difference in the *first cost* of light and heavy engines is at present, according to figures furnished to the writer by the Baldwin Locomotive Works, about as stated in the following table.

This is equal to a difference of about 33 per cent. in price for engines of double weight, and proportionally for less increase of weight. Other data, of perhaps less present value, would indicate the difference to be greater, or a little over 50 per cent. We may perhaps assume 40 per cent., and this item (the cost of renewals) forms a considerable portion of what appears charged to the cost of repairs. The "Renewal Fund" system of the Philadelphia & Reading Railroad enables us to determine that on that road the cost of renewals of engines is *at least* 29.7 per

Weight of Engine.	Approximate Cost			Per cent. of increase in total cost.
	Per long ton	Per ℔.	Total.	
20 tons...........	$350	15.6 cts.	$7,000	
30 "	275	12.2 "	8,250	17.9
40 "	230	10.3 "	9,200	31.4

cent. of the cost of repairs proper, or about 23 per cent. of "Repairs of Engines," including renewals, and very possibly more.* Of the remaining cost for "Repairs of Engines" (77 per cent. of the whole) which represents the expenditure for repairs proper; about 30 per cent. will be for wood, iron, steel, and other raw materials; 13 per cent. for wheels, axles and tires, and 57 per cent. only for labor, if we may judge by Table XIX. below. The cost of raw materials at least, and a certain portion of the cost of wheels and tires, should vary in almost direct proportion to the weight of engine, even if the cost of labor were independent of it, so that it would seem a moderate estimate that the cost of engine repairs (including, of course, renewals) is increased by about 33 per cent. for a double weight of engine.

The effect on the cost of *maintenance of track* of increasing the weight of engines is the most uncertain of all, and the writer knows of no observed facts bearing on the subject. It certainly increases in much greater ratio than the weight on the drivers, and as an estimate somewhere within gun-shot we might assume that it is approximately in proportion to the square of the weight of engine (*i. e.*, weight on drivers). For an engine of double weight, this would show that 100 per cent. additional power would be purchased at the cost of 300 per cent. increase in the cost of track maintenance per car hauled; but it would be an error to assume the percentage for so great a change in weight as a proper one for all changes. If the weight of engine be increased 10 per cent., the cost of track maintenance would be increased, under our rude assumption, *at the rate of* 210 per cent. ($1.1^2 = 1.21$, and $0.21 \times 10 = 2.10$); if it be increased 20 per cent., at the rate of 220 per cent. ($1.2^2 = 1.44$, and $0.44 \times 5 = 2.20$), etc. It is perhaps not an unfair assumption that the increase in track maintenance resulting from an increased weight on drivers is at the rate of 200 per cent. of the average cost, and that the cost of *ties and road-bed maintenance* will be in direct ratio, or at the rate of 100 per cent.; any excess in this estimate being covered by an unestimated increase in the cost of yards and structures.†

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* The "Renewal Fund" of the Philadelphia & Reading Railroad is formed by a direct tax of 5 cents per 100 ton miles, which does not appear in the returned "total expenses," as before stated, and appears to be expended—first, in making good the whole cost of new iron and bridges, and what is then left of it on rolling stock and structures. As it does not begin to cover the cost of car renewals, however (the returned expenditures for "renewals" being, for the four years—1869-73-74-75—only 4.4 per cent. of car repairs), it is uncertain how great a proportion of the *locomotive* renewals also is included in repairs. The *returned* cost of locomotive renewals is 29.7 per cent. of the returned cost of repairs, or about 22.8 per cent. of the total of renewals and repairs, as shown in Table XIX.

Summing up these estimates, we have as the cost of a double engine tonnage:

ITEM.	Total cost.	For a double NO. of engines.		For double WT. of engines.	
		Per cent increasing with No.	Cost.	Per cent increasing with w'gt.	Cost.
Fuel............	10 cts.	90 p. c.	9 cts.	50 p. c.	5 cts.
Oil, waste, etc..	2 "	"	21 "	" "	1 "
Engine rep'rs..	9 "	"		33 "	3 "
Train wages....	12 "	"		unaffected.	....
Track rep'rs....	13 "	100 p. c.	13 "	200 p. c.	26 "
Road bed rep'rs	7 "	"	7 "	100 "	7 "
Yards & struct's	7 "	includ'd above.	....	included above.	....
Gen. & stat'n..	30 "	unaffected.	....	unaffected.	....
Totals.....	$1 00	50 per cent.	50 cts.	42 p. c.	42 cts.

Assumed average, 48 cents per train mile, or 48 per cent. of operating expenses.

As an average between these two estimates, we may assume that the cost of so increasing any grade that a double engine tonnage will be required for the same business is 48 cents *per train mile required for a given business on the given grade.* Or, to express the same fact differently, 48 per cent. of the total operating expenses varies directly with the engine tonnage, the car tonnage remaining constant.

Assuming, then, an average of 48 cents per train mile, and multiplying by 325 for the number of yearly trips, and by 2 for the round trip, we have

$$\$.48 \times 325 \times 2 = \$312.00$$

as the yearly cost, *per daily train, per mile of road,* of increasing any ruling grade till the net load of the engine is reduced one-half. If, now, we multiply this sum by the *percentage* of increase in engine tonnage, resulting from an increase of ONE FOOT in any ruling grade, we shall obtain the cost per daily train per mile of road of such increase.

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† The authority by which we assume that the cost of road-bed repairs does in fact vary very nearly with the engine tonnage is given at length in the first paper of this series. The writer is well aware that it may appear excessive to many readers.

TABLE E.

SHOWING THE CAPITALIZED VALUE PER DAILY TRAIN OF AVOIDING AN ADDITION OF ONE FOOT TO THE RULING GRADE.

TABULATED FOR A ROAD 100 MILES IN LENGTH. REDUCE OR INCREASE IN PROPORTION TO LENGTH OF ROAD OR DIVISION.

(Cost per train mile assumed at $1.00.)

Rate of maximum grade in feet per mile	LEVEL.	10	20	30	40	50	60	80	100	150
Percentage of increase in engine tonnage, for each foot of increase in rate of grade (from Table D)..	4.0	3.1	2.4	2.0	1.7	1.5	1.4	1.2	1.1	0.9
COST PER YEAR OF ONE FOOT INCREASE IN RATE OF GRADE = $312.00 × 100 miles × per centage in line above	$1,248 00	$967 20	$748 80	$624 00	$530 40	$468 00	$436 80	$374 40	$343 20	$280 80
CAPITALIZED VALUE.										
Rate of interest, 5 per cent	$24,960	$19,344	$14,976	$12,480	$10,608	$9,360	$8,736	$7,488	$6,864	$5,616
Rate of interest, 6 per cent	20,800	16,120	12,480	10,400	8,840	7,800	7,280	6,240	5,720	4,680
Rate of interest 7 per cent	17,830	13,817	10,697	8,914	7,577	6,686	6,240	5,349	4,903	4,011
Rate of interest, 8 per cent	15,600	12,090	9,360	7,800	6,630	5,850	5.460	4,230	4,290	3,510
Rate of interest, 10 per cent	12,480	9,672	7,488	6,240	5,304	4,680	4,368	3,744	3,432	2,808
RELATIVE NUMBER OF TRAINS (or engine tonnage) required for same business	1.00	1.41	1.83	2.27	2.73	3.21	3.72	4.80	5.96	9.56
RELATIVE NET LOAD per engine ton	1.00	0.711	0.546	0.440	0.365	0.311	0.269	0.208	0.168	0.105

This cost, however, is not an absolute value independent of the length of the road, as in the case of the similar values deduced for distance, curvature, and rise and fall, but varies with it, inasmuch as the ruling grade increases the expense of operating the entire road, whatever its own length may be. Hence, to obtain the true value of reducing grade, it must be multiplied by the length of the road, since it is obvious that the justifiable expenditure to reduce grade will be twice as great on a road of 100 miles long as on a road of 50 miles long. We have made up Table E below for a road of 100 miles long as a convenient unit—equally so with one mile for the determination of values for any length of road, and giving at a casual glance a fairer comparison of the value of reducing grade with improvements in the other details of alignment. Table E embodies the final results we have been seeking, and its construction will now be sufficiently clear by an examination of the table itself.

THE PROPORTION OF BUSINESS AFFECTED BY A REDUCTION OF RULING GRADE.

It is very evident that inasmuch as the objection to high rates of grade lies solely in their effect as a limiting agent to the weight of trains, Table D cannot be applied indiscriminately to all trains run over the line, but only to such

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REMARKS ON TABLE E.—If the cost per train mile be higher or lower than $1.00, multiply the values above by the actual or assumed cost. Multiply also by the length of the road ÷ 100; and by the number of feet per mile in the proposed change of rate.

For an original rate of grade intermediate between those given in the table, the proper tabular values will be given, very nearly, by proportional interpolation—*e. g.:* Value of avoiding 1 foot per mile addition to a 15-feet grade, at 6 per cent. ($16,120 + $12,480) ÷ 2 = $14,300. True value: $312.00 × 100 × .027 = $842.40 ÷ .06 = $14,060.

For values PER $1,000 OF AVERAGE ANNUAL TOTAL EXPENSES PER MILE, increase the tabular values by one-half. (More exactly, multiply by 1.54.)

FOR ROADS IN OPERATION:

Tabular values *per* $100,000 *of average annual expenditures* on the given line or division, for various items, will be given as follows, and will be independent of the length:

Multiplying the tabular values above by	will give corresponding values, *per* $100,000 *of average annual expenditure*, for
1.5	TOTAL EXPENSES.
2.2	"Line" or "Transportation" expenses.
3.2	Maintenance of Way and Works, Repairs Engines, Fuel, Oil, etc.
2.8	Main. of Way and Works and "Motive Power" (same as above + engine wages).

This table is nearly independent of the pattern of engines, ratio of adhesion, rolling friction, or extent of the change of grade. The percentages of extreme error are the same as for Table D, which see.

TABLE F.

SHOWING THE CAPITALIZED VALUE PER LOADED CAR (20 tons) OF AVOIDING AN ADDITION OF ONE FOOT TO THE RULING GRADE. TABULATED FOR A ROAD 100 MILES IN LENGTH. REDUCE OR INCREASE IN PROPORTION TO LENGTH OF ROAD OR DIVISION. Cost per train mile assumed at $1.00.

Rate of Maximum Grade in feet per mile ☞	LEVEL.	20	40	60	80	100	120	150	200
No. of cars to a train, assuming 60 as the level load	60.0	32.8	22.0	16.2	12.5	10.0	8.3	6.3	4.2
PERCENTAGE OF INCREASE IN ENGINE TONNAGE, for each foot of increase in rate of grade (from Table D)	4.0	2.4	1.7	1.4	1.2	1.1	1.0	0.9	0.8
COST PER CAR HAULED OF ONE FOOT INCREASE IN RATE OF GRADE; = $0.48 × 2 × 100 miles × percentage in line above ÷ No. cars per train	$0.064	$0.070	$0.074	$0.083	$0.092	$0.105	$0.116	$0.137	$0.183
CAPITALIZED VALUES.									
Rate of interest, 5 per cent	$1.28	$1.40	$1.48	$1.66	$1.84	$2.10	$2.32	$2.74	$3.66
" " " 6 " "	1.07	1.17	1.23	1.38	1.53	1.75	1.93	2.28	3.05
" " " 7 " "	0.91	1.00	1.06	1.19	1.31	1.50	1.66	1.96	2.61
" " " 8 " "	0.80	0.87	0.93	1.04	1.15	1.31	1.45	1.71	2.29
" " " 10 " "	0.64	0.70	0.74	0.83	0.92	1.05	1.16	1.37	1.83

REMARKS.—If the cost per train mile be higher or lower than $1.00, multiply the values above by the actual or assumed cost. Multiply also by the length of the road divided by 100 and by the number of feet per mile in the proposed change of rate.

For a rate of grade intermediate between those given in the table, the proper tabular values will be given, very nearly, by proportional interpolation.

The table is calculated by an engine of 60 tons gross weight, including tender. For lighter engines the tabular values should be increased by 5 to 10 per cent. per 10 tons less weight.

For values PER $1,000 OF AVERAGE ANNUAL TOTAL EXPENSES PER MILE increase the tabular values by one-half. (More exactly, multiply by 1.54.)

FOR ROADS IN OPERATION

Multiply the tabular values by the same coefficients for various items of expense as given beneath Table E.

trains as it does *in fact* so limit. This, on a new road, might sometimes exclude *all* trains, and it would probably exclude a considerable proportion of all the passenger trains of the United States, which on a majority of railways habitually "run light." But as a railway is located once for all, Table E might perhaps be properly considered as applying to all freight trains, and in these days of increasing luxury of travel, to most passenger trains also, independent of the following important fact, which is often forgotten or neglected, viz., that, except for the grade, the weight of engine may be less for *all* trains, whether they commonly "run light" or not. Engines must always be heavier than is *ordinarily* required, to provide for occasional demands, and a reduction of ruling grade may properly be considered as reducing *pro rata* the necessary and advisable weight of engines, even for light trains. For it is certain that a 30-ton engine will haul no greater net load on a 60-feet grade than a 26-ton engine will haul on a 50-feet grade or a 22-ton engine on a 40-feet grade, and *whatever* may be the margin deemed proper as an allowance for emergencies or future increase of business, it must *always* be proper to reduce the engine tonnage in corresponding proportion; and hence a reduction of ruling grade has a positive and present cash value, even if every train upon the road will habitually be "run light" for an indefinite number of years. That this reduction is *not* made, and that, on many low-grade railways, locomotives of equal weight and power with those on lines opposing more than double the resistance are hammering out the track to no purpose whatever, is not the fault of the constructing engineer, nor is it good practice for him to adjust his alignment on the hypothesis of an error of judgment in those who succeed him.

On account of these facts, and of the grave disadvantages which are liable to arise at any time from an irremediable limitation of capacity, and also because a varying but usually important increase in way receipts is derived from additional

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Table F is nearly independent of the *extent* of the change in grade. The percentages of errors are the same as for Table D, which see. It is absolutely independent of the *rolling friction*, provided the assumed net load on a level be changed in proportion thereto. It is very nearly independent of the *pattern of engine and ratio of adhesion*. For the "Consolidation" pattern (or any engine weighing only 8 times the tractive power) decrease the values for a 60 feet grade 10 per cent., and grades of 100 feet and over 17 to 20 per cent For the "American standard" pattern (or any engine weighing 12 times the tractive power) increase in the same proportion. This is assuming the net load on a level to be 60 cars in each case. If less or greater, the tabular values will be changed in the same proportion.

length, but never from heavier gradients, the writer suggests that no more than due weight is given to the value of low grades if it be considered as applying to all trains alike—at least in original location and for the purpose of comparison with the value of improvements in the other details of alignment. In the case of projected improvements for railways already in operation and fully equipped with rolling stock, the case may be somewhat different.

Table D *apparently* indicates that the value of reducing the ruling grade decreases as the grade is higher. This is true, however, only *per train*, and is because *the number* of trains required to do a given business is greatly increased by heavy grades; or, more exactly speaking, because the *relative* net load decreases less rapidly on higher grades. For example, it will be seen, by referring to Table XVII., that an increase of 24 feet from a level grade halves the net load of the engine, while it requires an increase of 57 feet from a 50 feet grade to do the same. The reverse is the case, however, with respect to the COST PER LOADED CAR, which is the true ultimate measure of the cost of high gradients—the value per daily train being merely for *convenience* and to afford a uniform basis of comparison with the value of other improvements in alignment. The cost of increasing grades per loaded car is considerably greater as the grade is higher, because on the higher grades the cost of the constant addition to the engine tonnage which is necessitated by a given increase in grade is distributed among a less number of cars. Tables D and E furnish us a ready mode of approximating to the value per loaded car of reducing grade, as follows:

VALUE OF REDUCING THE MAXIMUM GRADE PER LOADED CAR. —We will assume, in order to err on the safe side, that an average engine will weigh as much as 60 tons including tender, and haul as many as 60 loaded cars on a straight and level track. Mr. A. J. Cassatt, Vice-President and late General Manager of the Pennsylvania Railroad, reported to Mr. Herman Haupt that the average load for a 63-ton engine is only 50 cars on a level on that road; but this is probably owing to the limiting effect of curvature, as the rolling friction deduced from the loads on higher gradients reported by him would indicate a level load of from 60 to 65 cars. A table prepared by Mr. J. Dutton Steele, late Chief Engineer of the Philadelphia & Reading Railroad, indicates that a 43½ ton engine will haul only 38 cars on a level. Mr. B. H. Latrobe's estimate before referred to for the Portland & Ogdensburg Railroad would indicate that a 65 ton engine, 42 tons on drivers, will haul only 50 loaded cars on a level. But this is assuming only 1-7 adhesion, an assumption on which we have already commented. Assuming 1-5 adhesion, it would haul 70 cars, a little over one car per ton of engine *

Assuming then 60 cars as the level load, Table XX. shows the corresponding number of cars to a train on different grades. This is computed directly from the column of net loads given in Table XVII. by first determining the percentage of the net load on each grade to the level load and then multiplying this percentage by the assumed level load, and it is evident that the numbers thus obtained are *relatively* correct, whatever may be the number hauled on a level. If the number be assumed to be greater or less for the same engine, the values obtained per car load will be in inverse ratio to the level load. If, however, the level load be less on account of a difference in the weight of engine, the effect upon the value of reducing grade is less important, since the use of engines of great weight is very nearly as expensive as a corresponding increase in their number.

Given then the number of cars to a train on each grade, we have already estimated that the cost per train mile for the items effected by an increase of ruling grade is 48 cents, or $96 per round trip of 100 miles. We also have in Tables D and E the percentage of increase in motive power which results from an increase of one foot in the ruling grade. Then,

$$\left\{\frac{\$96}{\text{No. of cars to a train}} \times \begin{array}{c}\text{per cent. of increase of motive power}\\ \text{per foot added to the grade}\end{array}\right\} =$$

the COST PER CAR-LOAD of one foot increase in ruling grade as given in Table F. This cost, divided by the rate of interest, gives the corresponding capitalized values.†

If it is desired to compare Tables E and F, the tabular values of Table F, × the number of cars to a train, × 325, for the number of days in the year, will give the corresponding values per daily train in Table E, as it is evident they should do. Any difference will be due to error from neglected decimals.

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*The basis for all these statements will be found in the Appendices to Vose's "Manual for Railroad Engineers."

† At this point we deem it proper to point out an error in a paper by J. G. Clarke, C. E., "on the Approximate Value of a Reduction of Ruling or Maximum Grade," stated to be based on data furnished by the late Charles Ellet. (See Trans. Am. Soc. Civ. Engrs., Apr., 1874. Also Van Nostrand's Magazine, vol. x., p. 37.) In so doing we disclaim once for all any intention or desire to pick flaws in the work of others, but deem it an equally essential part of a discussion of this kind to point out the grounds for any important differences from previous estimates of equal or greater authority, without forcing upon the reader the necessity of a special investigation for an intelligent decision. Mr. Clarke deduces in a very simple manner the following

It will be seen that we have not considered passenger business in this estimate per car-load, although for reasons

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short and convenient formula: Letting x and x' = the new and old rates of grade, W = the gross tonnage annually up the maximum grade, and T = the gross load an engine can draw on a level; the cost per mile of road of any change in the rate of any grade

$$= \frac{x'-x}{20T} W$$

Reduced to its lowest terms and dropping the algebraic nomenclature, this formula is equivalent to saying that the yearly cost of one foot increase or decrease in the rate of any grade is equal, in dollars per mile of road, to 1-20 of the number of trains necessary to haul the given business on a level; or, for a road 100 miles long, to *five times* the number of trains necessary on a level.

In this form it is somewhat easier to see that Mr. Clarke's formula is based upon a plausible fallacy, which consists in the *practical* assumption that because the value of reducing any two grades, say 20 and 40 feet, to a level is very nearly as the number of feet per mile reduced, *therefore* the value of reducing by the same number of feet any other two grades, say 40 and 60 feet to 20 feet, is not only as the number of feet of reduction as before, but is also the same in amount; whereas it increases considerably as the grades are higher, as is evident in Table F. We can show this also by a numerical illustration based upon the data of Mr. Clarke's own example, as follows:

Grades in feet per mile.	No. of loaded cars to a train, by Col. Seymour's table.	Corresponding No. of yearly trains required to move 11,280 car-loads of 10 tons each.	COST OF DO. per mile of line at 80 cents per mile round trip.	INCREASE IN COST on a grade 10 feet higher.	Do. capitalized at 7 per cent. = value per mile of 10 ft. reduct'n in grade.	Correspond'g value of 10 ft. reduction for a road 145 miles long.
30	30 5	370	$296 00	$64 80	$925 70	$134,226
40	25.	451	360 80	79 20	1,131 40	164,083
50	20.5	550	440 00	89 60	1,280 00	185,600
60	17.	662	529 60	70 40	1,005 70	145,827
70	15.	752	601 60	92 80	1,325 70	192,226
80	13.	868	694 40	......	....	....
By Mr. Clarke's formula, we obtain a UNIFORM value for a 10 feet change in any grade of				$60 00	$857 14	$124,285

The latter value is correct for changes from a *level* grade (according to Mr. Clarke's premises), but for no other. It is about 20 per cent. less than the values given in Table F for changes in a level grade, owing solely to the fact that Mr. Clarke assumes that the cost of additional engine tonnage is only 40 cents instead of 48 cents. On this and one or two other minor matters we need not stop to comment.

already given it appears to the writer that in most cases it should be so included. The weight of an ordinary passenger car for 60 persons is about 19 tons empty and 4 tons for a full load of passengers. Many sleeping cars weigh 30 and 40 tons, It would seem a very moderate estimate to consider the cost of an increase of grade per passenger car as equal to twice that per freight car, if not $2\frac{1}{2}$ or 3 times.

TABLE XIX.

Showing the Relative Cost of Renewals and Repairs of Engines, and the Relative Cost of Labor and Material for Repairs of Engines and Cars, on the Philadelphia & Reading Railroad, for a series of years.

YEAR.	Relative cost of renewals and repairs of engines.			Relative cost of labor, raw material, and wheels, axles and tires, for repairs of engines and cars, renewals not included.			
	Renewals.	Rep'rs proper	Total of renewals and repairs.	Labor.	Raw material.	Wheels, axles and tires.	Total.
1869..................	26.1	73.9	100.	57.3	30.6	12.1	100
1873..................	16.9	83.1	100.	54.9	31.3	13.8	100
1874..................	28.0	72.0	100.	56.3	30 0	13.7	100
1875..................	20.0	80.0	100.	58.1	28.5	13.4	100
Average..............	22.8	77.2	100.	56.7	30 1	13.2	100

			Average No. of engin's.
	Total yearly cost per engine on Philadelphia & Reading Railroad for repairs proper..............	$1,239	
	Total yearly cost per engine on Philadelphia & Reading Railroad for renewals....................	370	
	Total yearly cost per engine for "repairs of engines" as ordinarily understood........................	$1,609	378
Average of 1872–3–4 & 5	Total yearly cost per engine for "repairs of engines" on Penna. R.R. and branches	1,517	594½
	Total yearly cost per engine for "repairs of engines" on Phila. & Erie R. R..................................	1,333	147
	Total yearly cost per engine for "repairs of engines" on Un. R. R of N. J.................................	1,300	231½

REMARK.—The yearly cost of repairs *per engine* must not be confounded with the cost of repairs per train mile. The relative economy of the various railroads above in the latter respect would be in nearly inverse order to that shown in the cost of repairs per engine.

As a Practical Example of the Use of Tables E and F: By the Report of the Pennsylvania Railroad for last year, 1875, the movement of loaded cars between Pittsburgh and Altoona was about 255,000 eastward and about 85,000 westward, the remaining 170,000 cars returning empty. The average number of cars to a train on that division, coming east, is reported to be from 16 to 17, which would give the number of daily freight trains on that division as about 47. The distance is 118.3 miles, and includes the heaviest grades on the road, viz., 95 feet per mile going west from Altoona, for a distance of about 12 miles, and 53 feet per mile for the remainder of the distance. The maximum grade coming east is at several points 53 feet per mile. Assuming for the present that the latter is, independently of the use of assistant engines, a ruling grade which fixes the weight of trains, what would be the justifiable expenditure to render the 53 feet grade to the rate of 50 feet per mile, at 6 per cent. interest for capital?

TABLE XX.

Showing the Percentage of the Net Load on different grades to the net load on a level, and the corresponding number of cars to a train, according to the average experience of American railways, as shown in Tables XV., XVI. and XVII.

Grade in feet per mile.	Net Wt. of train per ton of tractive power.	Per cent. of net load to load on a level.	No. of loaded cars to a train, assuming 60 as the level load.
Level.	190.	100.	60.0
20	103.8	54.6	32.8
30	83.6	44.0	26.4
40	69.5	36.6	22.0
50	59.1	31.1	18.7
60	51.1	27.0	16.2
70	44.8	23.6	14.2
80	39.6	20.8	12.5
90	35.4	18.6	11.2
100	31.8	16.7	10.0
110	28.7	15.	9.0
120	26.1	13.8	8.3
130	23 8	12.4	7.4
140	21.7	11.4	6.8
150	19.9	10.5	6.3
175	16.2	8.5	5.1
200	13.3	7.0	4.2

By the *loaded car* standard, Table F, we have, interpolating the proper tabular value for 53 feet between the values given for 40 and 60 feet,

$1.33 ($1.38—.05) × 255,000 × 3 = $1,017,450, for a line 100 miles long and $1,017,450 × 1.183 for a line 118.3 miles long = $1,203,643.

By the *daily train* standard, Table E, we have, interpolating as before the proper value for a grade of 53 feet, between the values for 40 and 50 feet,

$7,644 ($7,800—$156) × 47 × 3 = $1,077,804 for a line 100 miles long and $1,077,804 × 1.183 = for a line 118.3 miles long, $1,275,042.

The latter estimate is about $72,000, or 6 per cent., greater than the former. This is partly owing to neglect of decimals in several places in computing the tables, but mainly to the fact that Table F is computed on the assumption of 18 cars to a train on a 53 feet grade, while in fact on the Pennsylvania Railroad it is only 16 or 17. This increases the number of trains required, and hence makes our estimate per car unduly low. As the average cost of a train mile on the Pennsylvania Railroad is slightly over $1, we may conclude that $1,300,000 is very near to what would be the present value to the road, taking into account freight business only, of reducing their 53 feet grades to 50 feet; except for the fact that it is the 95 feet grade going west and not the 53 feet grade coming east, which is really the ruling grade, independent of the use of assistant engines. This brings up another very important subject connected with gradients, viz., the proper balance of ruling grades for, an unequal traffic.

THE PROPER BALANCE OF MAXIMUM GRADES FOR AN UNEQUAL TRAFFIC.

An engine which has carried a full load in one direction must return at very nearly the same expense whether it be fully loaded or not. If therefore the traffic is permanently heavier in one direction than in the other, or there is just reason to expect that it will be, the grade opposed to the returning traffic may be made heavier than that in the opposite direction by an amount sufficient to make the resistance of trains, and hence the requisite motive power, the same in both directions. No advantage whatever results from reducing the return grade below this (beyond the inconsiderable amount which may be justifiably expended to reduce the rate of *any* grade, as pointed out under the head of Rise and Fall), and a very great economy may often be effected in construction. This problem is one of the simplest connected with railway location, yet it is also one of the most neglected—especially when the probable difference in weight of business is small—and this is largely due, as the writer believes, to an impression that it is a problem of much uncertainty and greatly affected by the pattern of engine, condition of track and rolling friction—an impression which is the reverse of the fact.

Table XVII. already given (page 442) furnishes us a ready means of making up a table (Table G, below) giving the proper balance of ruling grades for any given inequality in traffic—without calculation and in a simple and evident manner—and at the same time the means of determining the effect of variations in the pattern of engine, ratio of adhesion, etc. For example, if the grade opposed to the heaviest traffic be 20 feet per mile, the net load of cars and freight which an engine will draw up that grade in addition to its own weight is—by the fifth column of Table XVII.—103.8 tons per ton of adhesion or tractive power. If, in returning, the total weight of cars and freight will be only 0.5 or 0.8 as much, the load on the engine will be only 103.8 × 0.5 = 51.9 tons, or 103.8 × 0.8 = 83.04 tons, per ton of traction, and the grades up which the same engine will haul those loads we see by Table XVII. to be 59 feet and 30 feet per mile. In this way Table G was compiled.

In computing Table G it is obviously necessary to take the total weight of cars and freight each way, inasmuch as the empty cars must be hauled back whether full or empty. To determine the corresponding disproportion in freight only: if the cars be taken as of equal weight with the average full load, we have as the full load, car 1.0 + freight 1.0 = 2. Then if the ratio of the gross return load be 0.7, we have

0.7 × 2 = 1.4 — 1 (for car) = 0.4

as the corresponding ratio of return *freight only*. If the car be assumed to weigh only 0.8 of average full load, we have

Car, 0.8 + freight 1.0 = 1.8; × 0.7 = 1.26; — 0.8 (for car) = 0.46

as the corresponding ratio of return freight only. Table G is headed, for convenience, with these corresponding ratios of return freight only, in addition to the ratio of the gross weight of cars and freight.

Now, to determine the data given at the foot of Table G, as to the effect of a different pattern of engine, etc., let us suppose that the engine, instead of weighing only ten times its adhesion or tractive power, is of the "American Standard" pattern and weighs 12 times its adhesion. The net load per ton of traction, given in the fifth column of Table XVII., will then be decreased throughout by two tons. Hence, on a 20 feet grade, such an engine will haul 101.8 tons per ton of tractive power, instead of 103.8 tons, as above. Then, if the ratio of the return load, including the weight of cars, be 0.5 or 0.8, the same as assumed above, the corresponding grades for an "American Standard" engine will be found to be 58 and 30 feet per mile, instead of 59 and 30. If the grades were figured out to tenths, the exact difference would be found to be 1.4 feet in the first case, and 0.4 feet in the second case.

In this way we may test the effect of any number of different assumptions, with the results shown at the foot of Table G; and we shall finally reach the conclusion that the proper *balance* of ruling grades approaches nearer to being absolutely independent of variations in the weight or pattern of engines and cars, condition of track and rolling stock, rolling friction, ratio of adhesion, or other external conditions, than any other question connected with railway location; the extreme variation for any reasonable or probable variations in any of the above respects, and for the largest probable disproportion of traffic, being only 1 to 3 feet per mile on grades below 100 feet, and a little more above that. There would seem to be a general impression that, on the contrary, this is a highly uncertain and dubious question, varying widely with the premises assumed. At least this may partly account for the fact that the whole subject is so commonly neglected, and for the further fact that, if we may judge existing railways, when a solution is attempted it is so frequently erroneous. As a prominent example of this tendency to error, we may notice two recent estimates, which, in combination with each other, constitute the instruction proffered on this subject in Vose's "Manual for Railroad Engineers." Each of these estimates differs widely from Table G, but each of them also contains grave numerical errors. They also differ widely from each other, and with rather distracting effect to the inquiring student, as their errors are in opposite directions. We have felt bound to correct these estimates in detail in the foot note below, as they have been widely reprinted elsewhere, and more especially because the weight of the distinguished names connected with them would otherwise undoubtedly cause the conclusions of the present writer to be rejected without the formality of an examination. It will be seen, however, that they agree closely with each other, and with Table G, when their numerical oversights are corrected.*

EFFECT OF UNEQUAL GRADES ON PASSENGER TRAFFIC.

It is to be remembered that unequal grades are always objectionable for passenger business, since the weight of passenger trains is necessarily the same, or nearly so, each way. Therefore there is always a certain value in reducing the higher rate of grade, although it may be quite unobjectionable for the unequal freight traffic, or even offer less resistance than the lower rate of grade in the opposite direction. In such a case the value of reducing the rate of the maximum grades is divided between the two—being so much for each daily *passenger* train on the *higher* rate of grade, and so much for each

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* The estimates referred to (See Vose's Manual for Railroad Engineers' Appendix on "Balance of Grades for an Unequal Traffic") are for the Portland & Ogdensburg Railroad and for the Shenandoah Extension Railroad. The first assumes a 42-ton (of 2,000 lbs.) engine, all on drivers, and a 23-ton tender, or 65 tons in all; 1-7 adhesion (12,000

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lbs.) and 12 lbs. per ton rolling friction. With these data, the load of cars and freight which the engine can draw is :

On a grade of	Tons of 2,000 lbs.	Instead of—(as given by estimate)	Formula.
116 ft. per mile	149.5	170	$\frac{12,000}{12 + 43.94} - 65 = 149.5$
150 " " "	109.4	117	$\frac{12,000}{12 + 56.82} - 65 = 109.4$
200 " " "	71.75	77.5	$\frac{12,000}{12 + 75.76} - 65 = 71.75$

These errors materially alter the balance of ruling grades. It was assumed that there would be 3 tons east to 1 ton west, in cars of equal weight with a full load. With those premises, the proper balance is:

Grade per mile GOING WEST.	Corresponding grade coming east.			Formula, with data of estimate.
	Given by estimate	Deduced from data of estimate	According to Table G.	
116 ft.	63 ft.	78.3 ft.	78 ft.	$\left\{\frac{6\text{-}4 \times 149.5 + 65}{12,000} - 12\right\}\frac{5,280}{2,000}$
150 "	93 "	106.8 "	106 "	$\left\{\frac{6\text{-}4 \times 109.4 + 65}{12,000} - 12\right\}\frac{5,280}{2,000}$
200 "	136 "	152.0 "	149 "	$\left\{\frac{6\text{-}4 \times 71.75 + 65}{12,000} - 12\right\}\frac{5,280}{2,000}$

Even accepting the estimate's loads above as correct, the proper balance of grades would not be as it gives it. They would then be 67.3, 100, and 143 feet, instead of 63. 93, and 136, as above. In construction 116 feet grades going west and 63 feet coming east were adopted, instead of the true balance of 116 and 78 feet.

The estimate for the Shenandoah Valley Extension grades daily *freight* train on the lower rate. For example, let us suppose that the grades on any road are 50 and 64 feet, and that the ratio of the weight of freight trains in opposite directions is the same as on the Pennsylvania Railroad, viz. as 1 to 0.7. Well adjusted grades for the freight business would be (by Table G) 40 and 64 feet; well adjusted grades for the passenger business would be 50 and 50 feet. There is therefor a certain advantage, and hence a certain justifiable expenditure, to reduce *either* rate of grade, although the other remain constant. The value of reducing the 50-feet grade to 40 feet is so much per daily freight train or per freight car (given in Tables E and F); while on the other hand the value of reducing the 64-feet grade is so much per daily *passenger* train (also given in Table E), since it fixes the weight—not of the passenger *trains*, which are unchangeable—but of all passenger engines. When Tables E and F are thus applied, however, to passenger or freight trains exclusively, there is a certain error, because they were made up for an average of both passenger and freight business. The true values per *freight* train would be about 10 per cent. greater than in the table, and per *passenger* train about 20 per cent. less.†

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will be corrected most quickly by reprinting an extract with corrections in brackets:

"If the gross load of a train on a 30-feet grade be 541 tons, engine and tender being 63 tons, the cars and contents will weigh 478 tons; or, if 18,000 lbs. be allowed for each car and 22,000 lbs. for the load, then the number of cars will be 27 [22.9] and the net load 297 tons [262 9 tons;—The engineer making the estimate has distributed up the *weight of his engine* between cars and freight].

"The grade requiring double power to that required on a 30-feet grade will be 84½ feet [73 feet—formula:

$$\frac{11{,}160 \times 2}{9.2 + .38x} = 541 + 63, \text{ whence } x = 73, \text{ the same as in Table G].}$$

If the return cars be ¼ loaded the gross weight of trains will be 380 tons [343.8] and the corresponding inclination 53 feet [60.8:—by Table G, 61 feet]. The inclination that would employ the full power of an assistant engine to haul 380 tons [343.8 tons] would be 130 feet [147 feet]; but allowance must be made for the weight of the assistant engine. Making such allowance, 121 feet by data of the estimate, by Table K to be given hereafter, 119 feet.

† The writer originally attempted to determine separately the value of improvements in alignments for passenger and freight trains, but found it wholly impossible to do so, as *all* the attempted separations of expenses on different roads are necessarily in a large degree pure guess work, and fluctuate wildly. On the great east and west trunk lines the difference in cost per train mile is usually unimportant, and the same is true of the average of all the railroads of New York, if the "allotments" to passenger and freight business in the State Reports may be considered as having any value whatever. On such roads as the Illinois Central and the Louisville & Nashville,

Even if the business of a road consists of three distinct classes of traffic, viz., passenger, freight and mineral, each one of which would require a different balance of ruling grades, this difference need introduce no confusion in estimations of the value of reducing grades. For, if the number of daily trains in each class and the cost per train mile for each class be known or estimated, it will be seen at once by consulting Table G what class or classes of traffic any proposed reduction in grade will be valuable or worthless to, and an estimate may be made for each class separately, from Tables E and F.

THE EXTENT OF THE DISPROPORTION OF TRAFFIC ON VARIOUS RAILWAYS.

Few roads and no State reports give statistics in detail of the freight traffic in opposite directions. It is pre-eminently one of those questions which are easily enough determined for any particular railway by a special investigation of the facts on connecting or adjacent railways—and always *should* be so determined—but which cannot be investigated in any general form. We give below, however, in Tables XXI., some miscellaneous facts bearing on the subject. They are sufficient to show the general fact that on all the great east and west trunk lines, or on any other railways the business of which in one direction consists mainly in the transmission of cereals and other agricultural produce, the disproportion in traffic is very uniformly 3 or 4 to 1. They also show that this disproportion is subject both to sudden fluctuations and to a gradual and permanent change. A little investigation for any particular road, if extended over a period of years, will give very close indications as to the probable disproportion, and probably effect an important economy in construction, even if the disproportion be slight.

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the cost per freight-train mile would appear to vary from 10 to 20 per cent. above the average, and the same amount below for passenger trains. On the Philadelphia & Reading Railroad the cost per freight-train mile is about 10 per cent. greater than the average, per coal-train mile 60 per cent. greater, and per passenger-train mile 10 per cent. less, taking an average of the last five years. As a rude average between all this guess work there can be little doubt that the freight-train mile costs about 10 per cent. more, as a rule, than the average, and the passenger-train mile, about 10 or 20 per cent. less, and the value per train of improvements in alignment may be taken as differing very nearly in that proportion—as a balance between various considerations that we cannot now enter into. In many cases, however notably in New England, the passenger-train mile is reported as costing more than the freight.

PRACTICAL EXAMPLES OF THE ADJUSTMENT OF GRADES FOR UNEQUAL TRAFFIC.

As an *anti-illustration* we may take almost any railway at random. Let us take two of the most sagaciously located railways in the United States—the Pennsylvania and the Erie Railway. As stated in the last paper (page 457), the Pittsburgh Division of the Pennsylvania Railroad is 118.3 miles long, and has 53-feet grades each way, except for a few miles of 95-feet grade going west from Altoona. The latter is operated by assistant engines, and we pass it over for the present; but on the remainder of the division the weight of cars and freight westward is only 0.7 of that eastward, except in the immediate neighborhood of Pittsburgh. Therefore, if 53 feet were the lowest attainable grade coming east, any grade less than 80 feet going west would have been entirely unobjectionable, so far as freight business is concerned, and if the 95-feet grade had been reduced to 80 feet (as Mr. Herman Haupt says might easily have been done, in the address before the Massachusetts Legislature before referred to). the use of assistant freight engines might have been entirely dispensed with over the whole division. For a short distance near Pittsburgh, however, the

TABLE XXI.—A.

Showing the Ratio of Freight Westward to Freight Eastward on the Pennsylvania Railroad.

Year.	Freight only (excluding wt. of cars).			Freight and cars.
	Through.	Local.	Total.	
1859	0.80	0.57	0.62	0.81
1866......	0.51	0.47	0.48	0.74
1870...........	0.43	0.52	0.50	0.75
1873...........	0.37	0.17	0.22	0.61
1874...........	0.28	0.16	0.20	0.60
1875...........	0.35	0.15	0.19	0.60

REMARK.—This table is made up from the ton-mileage statistics, and hence is an average of the whole road. At Philadelphia the disproportion is much greater than shown above, while on the other hand at Pittsburgh the immense local mineral traffic has the effect of making the tonnage east and west very nearly equal. The movement of loaded cars, at Derry, 308 miles from Philadelphia and 47 miles from Pittsburgh, shows a disproportion almost precisely the same as that given above for through freight only.

The column of "freight and cars" was deduced from the previous statistics, by assuming the average load to be equal to the weight of cars. If greater, the ratio would of course be less.

grades westward should be no greater, or even less, than those eastward, if possible, on account of the local mineral traffic. All this could hardly have been foreseen with much precision at the time of the original location; but if the road were now to be entirely reconstructed and the number of trains of each class over different points of the line were known, it is altogether probable that the total cost of constructing the division could be considerably reduced, while at the same time its *value*, for operating purposes, would be very considerably increased.

TABLE XXI.—B.

Showing the Ratio of Freight North to Freight South on the Louisville & Nashville Railroad.

Year.	Percentage of increase or decrease in freight tonnage from previous year.		Ratio of Freight North to Frei't South.
	Southward.	Northward.	
1866—67			0.48
1867—68	— 7.5	+29 6	0.67
1868—69	+30.5	+39.8	0 72
1869—70	+51.5	+17.8	0.56
1870—71	+24.6	+29.4	0.48
Average.	+24.8	+29.15	0.582
1871—72	+30.2	+ 5.9	0.47
1872—73	+ 7.4	+51.5	0.67
1873—74	—11.0	— 1.4	0.74
1874—75	— 4.9	—12.8	0.68
1875—76	—15.9	+27.4	1.04
Average.	+ 1.16	+14.12	0.716
Average of entire period.	+11.66	+20.8	0.649

REMARK.—These statistics are deduced from the ton mileage of freight over main line. The great and sudden change in the ratio of freight north to freight south in 1875–6, it will be observed, is due to the co-operating effect of a large decrease in southward-bound traffic and a large increase in northward-bound traffic at the same time.

Averaging the above percentages of increase for each year does not give a strictly correct percentage for the average growth of business. If the traffic in each direction for the first and last year above given be taken, the average ratio of growth will be found to be 9.5 per cent. per year for south-bound freight and 19 1 per cent. per year for north-bound freight.

The same is true of the Erie Railway, although the writer would not be understood as questioning the consummate engineering skill with which that road was carried through the mountains and the wilderness, in the early days of the profession, without the tunnels and other engineering luxuries (always excepting the Starucca Viaduct) and with the most

TABLE XXI.—C.

Showing the Disproportion in Freight Tonnage in opposite directions on Various Railways.

NAME OF ROAD.	Year.	Disproportion in f't.		Remarks.
		East-ward.	West-ward.	
Boston & Albany.......	1867	1	0.38	Through freight only.
Lake Shore & M. S.......	1872	1	0.37	
Illinois Central..........	1864–72	>1	0 37	
Union Pacific..........	1875	1	2.33	Through freight only.
Portland & Ogdensb'gh	1865±	1	0.33	Est. of Engineer.
L. Ont. & Atlantic......	1868	1	0.25	" " "
Shen. Valley Extensions	1870	1	0.25	" " "

REMARKS: *Boston & Albany*—Statistics taken from an "Address on Transportation" before the Massachusetts Legislature by Edward Crane. The writer knows of no other or more recent source.

Lake Shore & Michigan Southern and Illinois Central.—Statistics taken from Mr. L. P. Morehouse's paper on "The Cost of Transportation on Railroads. For the Illinois Central, Mr. Morehouse states only that, for a period of 8 years, "the average train appears to consist of 9 loaded and 9 empty cars and the way car." If the cars were all loaded in one direction, this would require that they should return empty, and after making all allowances it would seem that the actual disproportion must be at least as great as on its eastern connections.

Union Pacific.—The way freight (more than double the through freight) is not separated into east and west bound. As illustrating the difficulty, in many cases, of forming correct estimates of future business; in 1865 it was estimated that the *wagon* tonnage westward was 112,000 tons yearly and was increasing at the rate of 200 per cent. It was estimated that this amount would be "increased enormously" and would be 300,000 tons "long before the road was completed." In 1875, *ten years* thereafter, the through westward tonnage was only 116,000 tons and the local tonnage westward about as much more. The immediate passenger traffic was estimated at the same time as 300,000 west and 250,000 east. It is now (1875) 137,000 west and 73,000 east.

Portland & Ogdenburg.—The estimate for this road has been already referred to. The writer has not the reference at hand to fix the date.

Lake Ontario & Atlantic: *Shenandoah Valley Extension.*—The former of these estimates is for a mythical road to connect Lake Ontario with the Hoosac Tunnel, and may be found in some remarks on Transportation before the Massachusetts Legislature, 1868. The latter was designed to extend from Russellville, in East Tennessee, northeasterly to Covington on the Chesapeake & Ohio. (See *Railroad Gazette*, July 5, 1873, page 267). It may therefore be taken as approximately fixing the disproportion on all the northeasterly trunk lines of Virginia.

sagacious adaptation of present means to future requirements. Nevertheless, the Erie Railway and its branches have lamentably ill-adjusted ruling grades at various points, apparently owing to the mistaken idea that if a lower grade can be secured at any point by a moderate expenditure it is always advisable. The Delaware Division ascends eastward out of Susquehanna on a 60-feet grade for 8 miles, thence descends on a 57 and 49-feet grade for about 7 miles to Deposit, and thence descends on a maximum of 15 feet per mile for 90 miles to Port Jervis, but this latter grade is in effect increased to 25

TABLE G.

SHOWING THE PROPER ADJUSTMENT OF RULING GRADES FOR AN UNEQUAL TRAFFIC *according to the average performance of Engines on all American Railways.*

GRADE OPPOSED TO HEAVIEST TRAFFIC, IN FEET PER MILE.	RETURN GRADES Offering an Equal Resistance if the ratio of the *gross weight* of cars and freight returning is					
	0.9	0.8	0.7	0.6	0.5	0.35
	Corresponding ratios of *freight only* in case of equal weight with a full load.					Coal cars of average weight returning empty.
	.8	.6	.4	.2	Empty	
	Ratio of freight only in cars weighing 0.8 of load.					
	0.82	0.64	0.46	0.28	0.1	
Level	2	6	10	16	24	43
5	8	12	17	24	33	54
10	14	18	24	32	42	66
15	19	24	31	39	51	77
20	25	30	37	47	59	88
25	30	36	44	54	67	98
30	35	42	51	61	76	108
40	46	54	64	76	92	127
50	57	66	76	90	107	146
60	68	77	89	104	122	163
70	79	89	101	117	136	179
80	89	100	113	130	150	195
90	100	112	125	143	164	209
100	110	123	137	155	177	223
110	121	134	149	167	190	237
120	132	145	160	179	203	249
130	142	156	170	191	215	261
140	152	167	178	203	227	273
150	162	177	195	212	238	304

REMARK.—This table is practically independent of any probable variations in the pattern of engine, ration of adhesion or rolling friction. The *extreme* variation resulting from any such variation in premises would be in the last two columns and about as follows :

feet at least by sharp curvature. Now in descending from the summit the low grade is attained by following down the hillside at a nearly constant elevation of about 40 feet above the valley, with much curvature, about one mile more of distance, and at least twice the cost per mile for construction which would have been necessary for a line located in the bottom of the valley on a grade of 60 or 70 feet per mile. This would have been quite unobjectionable in connection with the low-grade line eastwardly, as it would simply have more nearly consumed the power of the assistant engine necessary in any event, as we shall see when we reach the subject of assistant engines; and it will be seen by Table G that even 80 or 90 feet would be no more than equivalent to the 60-feet grade ascending eastwardly. In the same way, on the Eastern Division, the grades on the main summit east of Port Jervis are 46 and 60 feet, an approximately correct adjustment; but the advantage therefrom is largely neutralized by the short "Oxford grade" of 59 feet per mile for about three miles going east. This difference in grade is not sufficient for the economical use of assistant engines (although they are so employed to some extent), as only a frac-

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For a Rolling Friction 2 lbs. per ton less (8 lbs.)

Subtract from grade given opposite.	Under fourth column (0.7)	Under sixth column (0.5)	Under last column (0.35
Level	2	4	8
50	1	3	5
100	1	2	2

For a rolling friction 2 lbs. per ton greater (12 lbs.) *add* the same number of feet per mile.

For a different pattern of engine: "American standard" (or any engine weighing 12 times its tractive power).

Subtract from grade given opposite.	Under fourth column (0.7)	Under sixth column (0.5)	Under last column (0.35)
Level	0	1	2
30	1	2	5
60	2	4	9
90	2	6	14
120	4	9	22
150	5	12	..

For a "consolidation" (or any engine weighing 8 times its tractive power) *add* the same number of feet per mile.

For a tank engine (or any engine weighing 6 times its tractive power) add *twice* the number of feet per mile above, and for grades of 90 feet and over 2½ times.

tion of the power of an assistant engine can be used. Hence this short grade has the effect of limiting the weight of trains in both directions to a very considerable extent. If it were absolutely unavoidable, ruling grades of 59 feet east and 88 feet west should have been at once adopted for the entire division and freely used, wherever the cost of construction or the length of the line could be reduced thereby. In this way the cost of construction would have been very greatly reduced, several miles of distance saved, and the *operating value* of the line, as a machine to accomplish a certain end, not appreciably diminished even if it were not increased by the shortness of the line. On the Buffalo and Western divisions, and on many of the branches, also the ruling grades have been made the same each way at considerable expense and without any sufficient compensating advantage.

As a third example, we may take the Canada Southern Railway, which is located throughout with maximum grades of 15 feet per mile in each direction. In coming east this was secured without much difficulty, but in going west it was obtained only at a cost of over $100,000, a heavy crossing of the Grand River and one or two miles of distance.‡ Now for any useful purpose subserved, the additional cost of this developed location might far better have been thrown into the sea, for let us consider the value of the distance lost and the nature of the business of the Canada Southern. As it was built almost exclusively as a great through freight line to compete with the Lake Shore and the Great Western railways, it might reasonably assume a corresponding business both in amount and in character. By Table XXI.—C, the westward freight would probably be only 0.37 of the eastward, and the corresponding grade to 15 feet going east would be 35 feet. If a 35-feet grade west and direct line had been adopted, the value of each mile saved would have been, by Table A (page 379), at 7 per cent. for capital and for a business of 20 trains daily (less than the business of the Lake Shore road at that time) $3,900 × 20 = $78,000.

A final instance we may take from the location of a railroad in Western Pennsylvania which has a maximum of 26.4

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‡ The writer does not guarantee the exact correctness of these figures, but the facts were somewhere in that neighborhood. They have been given to him at much larger figures. Neither would he be understood as implying that the Canada Southern Railway is specially obnoxious to criticism in this respect. A little investigation on almost any railway will show that engines habitually do less work in one direction, but it is a very unobtrusive source of waste, and hence attracts little attention.

feet per mile coming east. The distinguished Chief Engineer of that road said in his report on the location of the line that "the maximum of 79.6 feet per mile going west being in favor of the great excess of east-bound tonnage will require no assistant engines, but be operated with a large surplus of power without their aid." Table G will show that this excess of tonnage would have to be great indeed, as the returning engines would not even be able to haul back the empty cars. It was an *absolute certainty* that assistant engines would be required on this road, independent of any possible differences in the character of the road-bed and rolling stock; but lest he might otherwise appear unjustified in such a statement, the writer has made inquiries and learns, as was wholly unavoidable, that assistant engines are regularly employed.

ASSISTANT ENGINES.

We know of no better introduction to this subject than the following remarks of Mr. Herman Haupt, in a paper on the adjustment of the gradients of the Shenandoah Valley Extension Railroad, published in *Van Nostrand's Engineering Magazine* for 1873, and also in the *Railroad Gazette* for July 5, 1873, page 267:

"The load of an engine on any working division is determined by the maximum resistance offered by grade and curvature, and except where assistant engines are employed no greater load can be carried over the division than can be carried over the point of greatest resistance. While, therefore, it may be expedient to make large expenditures to reduce the maximum resistances on any division, yet when these have been established it is not proper to sacrifice capital by reducing points of less resistance, as not a single car could thereby be added to through trains, or any appreciable economy of operations secured. * * * * * *

"This being understood, an attempt will be made to prove, contrary to the generally received opinion, that undulating gradients below the limits of maximum resistance are not objectionable, and that while admitting of great economy of construction they do not materially increase the cost of operation, as compared with uniform and low gradients between the same points; *also that the use of higher gradients for part of a given distance will often result in greater economy of operation than a lower and uniform gradient for the whole distance.*

"It was formerly the practice of engineers to compare different lines of railway by conceding a given amount of rise and fall as equivalent to a mile of distance. This is not correct practice. The profile of the line and the direction and amount of tonnage, or, in other words, the maximum resistances and their distribution over the line, are the elements to determine questions of relative economy of operation. The rise and fall affect the question very slightly.

"*If the maximum resistances can be concentrated at one point and overcome at once with the aid of assistant engines, while lighter gradients in favor of the direction of the tonnage prevail on all the rest of the route, the line will be operated cheaply. But if the maximum resistances are scattered over the whole line, at intervals more or less remote, the operation will be expensive.*

"*In the solution of the problems in railway economics it is not safe to apply general rules or principles too freely. Each line presents a problem in itself, the solution of which should depend on the particular data which the case presents; millions of dollars have been sacrificed by conforming to general rules and theories when circumstances required variations.*

"A practical illustration, having reference to the system of gradients recommended, will make this subject sufficiently clear to the practical reader. Suppose the gradient which determines the load of an engine over any division is of 30 feet to the mile, and that it would be practicable by an expenditure not excessive to locate a portion of the division with a uniform ascending gradient of 6 feet to the mile, but that by ascending at the rate of 36 feet to the mile for five miles and descending 24 feet to the mile for the remaining distance a large saving could be effected in construction. There are few perhaps who would not make a sacrifice to secure the lower gradient, and yet it can be shown that it has no advantages even in economy of operation over the undulating and much higher gradient."

These remarks are all sound in the highest degree, and in so far as they apply to the relative cost and disadvantages of ruling and minor gradients, we have already endeavored to enforce the same argument in previous papers, by pointing out the essential dissimilarity which exists between them, not only in their magnitude but in their character. We now proceed to consider the economical and engineering laws which govern the use of ASSISTANT ENGINES, premising that the great advantages which may be secured by their use under proper conditions, and the absolute necessity of careful attention to those conditions if we are to reap such advantages, is but little appreciated by many locating engineers. The possibility of using assistant engines should *always* be kept in view on low-grade lines and high alike, for the advantages on the former may be far greater than on the latter.

THE POWER OF ASSISTANT ENGINES.

By the use of assistant engines the limiting effect of even very high gradients is in effect reduced below that of very much lower ones on other points of the line, and it is evident that economy in motive power requires that these gradients should as nearly as possible balance each other in order that the true *ruling* grade may be the lower grade worked by one engine. Table K, below, shows these equivalent grades for either one or two assistant engines, whether of equal weight or heavier by a certain percentage.

TABLE K.,

SHOWING THE PROPER ADJUSTMENT OF RULING GRADES FOR THE USE OF ASSISTANT ENGINES, ACCORDING TO THE AVERAGE DAILY PERFORMANCE OF ENGINES ON ALL AMERICAN RAILWAYS.

RULING GRADE WORKED BY ONE ENGINE, in feet per mile.	Grade up which the same train can be drawn by the aid of—					
	ONE ASSISTANT ENGINE			TWO ASSISTANT ENGINES		
	of equal weight on drivers.	heavier by		of equal weight on drivers.	each heavier by	
		20 p. ct.	40 p. ct.		20 p. ct.	40 p. ct.
Level.	24	29	33	46	54	62
10	42	48	53	70	80	90
20	59	66	72	92	104	116
30	76	84	91	113	126	138
40	92	101	109	133	147	160
50	107	117	126	152	167	180
60	122	133	142	169	185	199
70	136	148	158	185	201	216
80	150	162	173	201	217	232
90	164	176	187	216	232	247
100	177	189	201	230	247	261
110	190	202	214			
120	203	215	227			
130	215	227	239			
140	227	239	251			
150	238	250	262			

Remarks.—This table is practically independent of all variations in the pattern of engine, ratio of adhesion and rolling friction. A lower rolling friction slightly decreases the grades for assistant engines, as follows:

For a Rolling Friction 2 lbs. per ton less, (8 lbs.)

Subtract from grades given opposite—	For 1 Asst. Engine.	For 2 Asst. Engines.
Level.	4	8
50	3	5
100	2	3

An increase in the ratio of adhesion above the average assumed (1-5) would also have the effect to slightly decrease the grades for assistant engines, by about 1-12 *of the maximum grade for one engine* when one assistant engine is used, and by about ⅛ when two assistant engines are used, *provided* the net load for one engine were increased in proportion; but as a matter of fact, trains are almost invariably made up on all railways to oppose a maximum resistance equal to 1-5 of the weight on drivers, and the variations either way are very slight.

A variation in the pattern of engine has only the effect of increasing the weight of the train by the amount by which the weight on the truck and tender is decreased. The above table is calculated allowing half the gross weight of engine and tender as available for adhesion ("Mogul" engine).

Table K requires no explanation or justification of the premises assumed (in respect to rolling friction, adhesion, etc.), because it is practically independent of all premises, with the inconsiderable variations set forth below it. It is deduced by inspection from the table on page 80, Table XVII., of which we have already made such frequent use, in the following obvious manner: On a grade of 30 feet per mile, for example, any engine will haul in daily practice 83.6 tons per ton of adhesion (*i. e.*, per five tons on drivers), as nearly as may be. If a "pusher" of equal weight be attached to that train, the net load per ton of adhesion is at once reduced to 41.8 tons. The grade up which an engine will draw 41.8 tons per ton of adhesion is, by Table XVII., 76 feet, which is the equivalent gradient required. If the pusher be 40 per cent. heavier, we have, to haul each 83.6 tons of net load, 2.4 tons of tractive power. Then $\frac{83.6}{2.4} = 34.83$ tons, and the equivalent gradient thereto is 84 feet. The process is so simple as to require no further explanation.

It is to be remembered in testing or applying the table that if the lower grade be complicated by unreduced curvature, according to a wasteful but common practice, it is in effect increased a very considerable amount. We shall consider this subject with some care in our next paper, and therefore will only add that a 6° curve is equivalent in its *limiting effect* on trains—although not in pounds of resistance to the short trains which it renders necessary—to a grade of 15 to 30 feet per mile.

THE DUTY OF ASSISTANT ENGINES.

This seems to be about 100 miles a day, if they *have a chance to run it*, and at least equal to, if not considerably in excess of, the mileage of ordinary through engines. The Philadelphia & Reading Railroad has a grade two miles long which is worked with two assistant engines weighing 36 long tons each, or from 10 to 20 per cent. more than the regular coal engines. These engines, in 1873 and 1874, pushed about 25 coal trains daily up the incline, making an average mileage of 31,500 miles a year, an excess of more than 50 per cent. over the average duty of all the engines on the road, which for three years was only 20,500 miles. In 1875, however, and also in 1867 and 1869 (the only years for which the writer has reports), the business was lighter and the two assistant engines were only able to make about 22,500 miles, thus increasing the expense somewhat, as will be seen by Table XXIII. But in those years the mileage of the other engines suffered from the same cause, for we find it amounting to only 17,600 miles, so that the mileage of assistant engines exceeded the average in those years also by a large percentage (28 per cent.) Mr. Benj. H. Latrobe, in a report on the location of the Pittsburgh & Connellsville Railroad (1868), gives the following opinion in reference to the duty of assistant engines: "On the seven miles west of the summit, engines will be assisted by auxiliary power, one of such helping engine being sufficient to take six or seven trains to the summit daily, as the long experience upon the Baltimore & Ohio Railroad at Parr's Ridge, 45 miles from Baltimore, has proved." Mr. Herman Haupt also, in an address before a committee of the Massachusetts Legislature before referred to, gives as the result of his long experience on the Pennsylvania Railroad that an assistant engine can be re-

TABLE XXII.

Showing the Average Duty of Engines, and the average proportion of time lost in repairs on various Railways.

NAME OF ROAD.	Numb'r of years averaged.	Average yearly mileage of engines.	Average percentage of engines in shops.	Numb'r engines in service 1875.
Pennsylvania	7	20,600	0.17	1,069
Philadelphia & Reading	4	19,200	0.08	410
Louisville & Nashville	4	20,200	....	118
Erie	4	25,700	0.10	461
New York Central	4	28,900	....	558
Lake Shore & Michigan Southern	2	24,700	....	495

REMARKS.—*Pennsylvania:* The high proportion of engines in shop is doubtless owing in large degree to extensive reconstructions of engines which have been recently in progress. The yearly mileage has increased about 30 per cent. since 1859. Distributing service (work trains) constitutes 4 per cent. of the total mileage.

Louisville & Nashville: The average mileage is for main line only, and also the number of engines. Total number, including branches, 1875, 215. The average mileage per engine for the whole road was in 1874–5 only 14,000 miles.

Erie: The mileage reported has been increased 4 per cent. to include work-train mileage not given in State reports. Engines reported as broken up were excluded.

New York Central: The very heavy mileage is owing in great degree to the enormous proportion of work trains (nearly equal to passenger service) while constructing quadruple track, although doubtless the recently adopted system of long runs co-operated. In 1867 the average mileage was only 19,500 miles. No deduction was made from the reported number of engines for engines broken up, as in the case of the Erie, as was thought to be just. Neither was any similar deduction made from the Lake Shore reports.

lied on to average five trips daily over a 10-mile incline, thus amounting to 100 miles daily duty, or about the same as Mr. Latrobe's estimate (84 to 98 miles) above. The writer has been unable to obtain any further data, but the estimates of both the distinguished engineers above are considerably over the duty which is realized in practice with ordinary locomotives, if we may trust the indications of the previous table, (Table XXII). It is very common to estimate the average duty of engines at 100 miles a day, or 30,000 miles a year. This is correct enough while the engine is running, but the *average* duty, including time lost for repairs, would seem in practice to be more frequently under than over 24,000 miles a year, or for 300 days in the year (leaving out 25 days as lost for repairs, which would perhaps more properly be 35 or 40 days) 80 miles a day. There would therefore seem sufficient reason to believe that assistant engines will realize a somewhat high-

TABLE XXIII.,

Showing the relative cost of operating the assistant and regular coal engines, on the Philadelphia & Reading Railroad, for a series of years.

Length of run for assistant engines (two for each train), 2 miles.

YEAR.	Miles of daily duty when in service.		Cost of fuel, oil and repairs per mile run.		Cost of fuel, oil, and repairs per day.		No. of daily coal trains.
	Asst. engine.	Reg. engine.	Asst. engine.	Reg. engine.	Asst. engine.	Reg. engine.	
1867........	60	95	$0.344	$0.291	$20.65	$27.56	15
1869........	71	95	0.287	0.285	20.37	27.06	18
1873........	96	95	0.295	0.251	28.30	22.91	24
1874........	97	95	0.296	0.250	28.76	23.70	24
1875........	69	95	0,270	0.282	18.65	26.82	17
Average..	78.6	95	$0.295	$0.272	$23.35	$25.61	....

REMARKS.—It is to be remembered that these engines are very expensive *per mile run*, as the admirable system of gradients of the Reading Railroad enables heavy trains to be drawn and the engine to work up to its full capacity at all points. The freight engines cost about 15 per cent. less to move ⅓ of the load, and the passenger engines about 33 per cent. less.

The two assistant engines weigh 36.3 long tons each, or 40.6 tons of 2,000 lbs. The regular coal engines are invariably of the same pattern and weight, viz.: 36 tons of 2,000 lbs., thus evincing a rare appreciation ef the economy of uniformity.

During the years covered by the table the same two assistant engines appear to have *actually made* the average daily duty on each working day of the year. On the other hand the regular coal engines appear to be in the shop about one month in the year.

The cost of *engine wages* for this period was six cents per mile for through engines, and from six to nine cents for assistant engines, according to average daily run.

er mileage than the average locomotive, when there are sufficient trains to keep them busy.

THE COST OF ASSISTANT ENGINES.

This is usually estimated by all engineers at about the same cost as for the engines in ordinary use. The previous table (Table XXIII.), however, would seem to indicate that the cost per mile run is somewhat higher for assistant engines, and the writer believes these statistics to be entirely trustworthy. It is to be remembered, however, that Table XXIII. does not show an important advantage of assistant engines, viz., that although the cost per mile run may be somewhat higher, assistant engines will realize a higher *yearly* duty than ordinary engines, owing to the nature of their service; and the saving in capital invested from this cause, if it exists, would nearly or quite make up the difference in cost per mile run. The writer has not been able to ascertain any further facts of this character, but the difference in cost, if any, must be trifling. Assuming this to be so, we have, as the cost per mile run of an assistant engine:

Direct Running Expenses	Fuel	10 cts.	
	Oil and water	2 "	
	Repairs	9 "	
	Wages	6 "	
			27 cts.
Maintenance of Way Expenses	Renewal of iron	7 cts.	
	Track repairs	6 "	
	Yards and structures	3 "	
	Roadbed rep'rs (58 p.c.)	4 "	
			20 "
Total cost of an assistant engine per mile run			47 "

The estimate of the cost due to maintenance of way has been made purposely large, to include the cost of the additional switches and buildings made necessary by assistant engines, for which it is impossible to make a general estimate.

Assuming then 47 cents per train-mile, *the additional cost per year per daily train if operating one mile of track with assistant power* will be

$0.47 × 2 × 325 = $305.50.*

This amount forms the basis for Table L—1, page 120, and is based upon an average mileage of about 80 miles a day, but if it be impossible to realize this mileage, owing to the special operating conditions, the cost of assistant engine service is but slightly increased. Thus, supposing assistant engines are only able to average 60 miles a day instead of 80 miles, we may estimate the cost per mile which *might* be run, if standing in

TABLE L—1.

SHOWING THE CAPITALIZED COST OF ASSISTANT ENGINE SERVICE PER MILE OF INCLINE.

(Average cost of a train-mile assumed at $1.00).

Rate of Interest on Capital.	Per daily train.	Per $1,000 of of annual expenses per mile.
5 per cent	$7,110	$9,400
6 "	5,092	7,833
7 "	4,364	6,714
8 "	3,819	5,875
10 "	3,055	4,700
YEARLY COST per mile of assistant engine service	$305 50	$470 00

REMARKS.—The sum given as the cost of assistant engine service per $1,000 of annual expenditure is simply equivalent to saying that the cost of assistant engine service is 47-100 of the average cost of a train mile as before determined. The sum given per daily train is 650-1,000 of this amount.

the yard with steam up, at about 25 per cent. of the cost while running, as follows:

	Cost per mile while running.	In yard with steam up.
Fuel	10 cts.	5 cts.
Oil and water	2 "	0 "
Repairs	9 "	1 "
Wages	6 "	6 "
Maintenance of way	20 "	0 "
Total	47 cts.	12 cts.

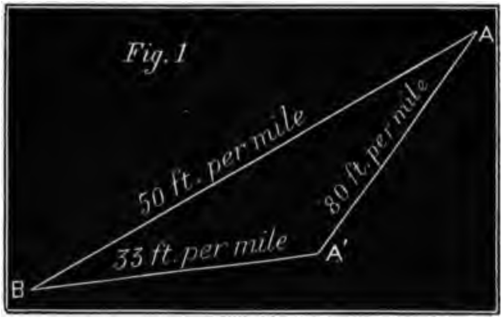
It appears from this that the cost of standing idle while 20 miles might be run is only equivalent in cost to about five miles of additional run, thus increasing the cost of assistant engine service by 5-60 or about 8 per cent. If the assistant engine makes 70 miles, the loss is only equivalent to 2.5-70, or 3.5 per cent. Under ordinary circumstances it would be very poor management which did not realize more than 60 miles a day from assistant engines, and as they are quite as likely to exceed the average mileage as to fall below it, this source of error may be neglected.

These data determined, we may now proceed to consider the question of

ASSISTANT ENGINES VERSUS UNIFORM GRADES.

If we have two alternate locations, A B, and A A′ B, Fig. 1, one of which it is designed to work with assistant power and one without, *by adopting the line with assistant power*, 1st. WE GAIN—what is equivalent to a reduction in the ruling grade—the amount of which will depend on the skill and good fortune with which the grades have been adjusted, but which should closely approximate to the difference between the gradients given in Table K, (page 115.)

2d. WE LOSE the cost of assistant power on the incline AA′; $305.50 yearly, per daily train, per mile of incline.



The problem being thus stated, the values which we have previously determined give us a ready and simple method of solving it. Thus if, in Fig. 1, we have estimated the probable number of daily trains required on the line having 33 feet maximum grade—for the 80 feet incline is reduced in limiting effect to 33 feet by the use of assistant engines—then by adopting the line having a uniform maximum grade of 50 feet we have in effect increased the maximum grade 17 feet per mile. Now, assuming the latter line to be 105 miles in length and the former 100 miles, with an incline of 10 miles to be operated with assistant power, the comparative operating value of the two alignments would be as follows, allowing the rate of interest on capital to be 7 per cent.:

In favor of the line for assistant engines, 17 ft. per mile saved in ruling grade, over 33 ft., value, by Table E, $8,513 × 17 × $\frac{105}{100}$ =	$151,957
In favor of the line of uniform gradient, 10 miles saved of assistant engine service, value, by Table L—1, $4,364×10=	43,640
Net difference in operating value—due to gradients only—in favor of the low-grade line; per daily train	$108,317
Value of 5 miles of distance in favor of line for assistant engines, by Table A, $3,900 × 5 =	19,500
Total difference in operating value, per daily train, in favor of low-grade line	$127,817

This process would seem to be simple enough, requiring only the intelligent application of formulæ already determined. But we may still simplify it by determining what we may call an *equating ratio*, given in Table L—2 below, which gives the distance per mile of road over which we may afford to use assistant power to avoid increasing the ruling grade *one foot per mile*. This ratio, multiplied by the entire length of the line and by the number of feet reduction in ruling grade which is in effect obtained by using assistant engines, gives the difference over which we can *afford* to use assistant power, and the difference between this distance and that actually required gives—when multiplied by the capitalized value per mile of the saving in assistant engine service—the difference in the operating value of the two alignments so far as affected by the gradients alone.

TABLE L—2

SHOWING THE DISTANCE PER MILE OF ROAD OVER WHICH ASSISTANT ENGINES MAY BE ECONOMICALLY EMPLOYED TO AVOID AN INCREASE OF ONE FOOT IN THE EQUIVALENT MAXIMUM GRADE.

MAX. GRADE other than that operated by assistant engines.	Cost per mile of line of increasing grade 1 ft.	Cost per mile of assist'nt engine service	Equivalent dist. for use of assistant engines; in miles per mile of line.
Level	$12 48	$305 50	0.0408
5	10 61	"	0.0347
10	9 67	"	0.0316
15	8 42	"	0.0267
20	7 49	"	0.0237
25	6 86	"	0.0225
30	6 24	"	0.0204
40	5 30	"	0.0173
50	4 68	"	0.0153
60	4 37	"	0.0143
80	3 74	"	0.0122
100	3 43	"	0.0112

REMARK. By comparing the above with the value of saving distance (Table A.) it will be seen that without essential error we may consider that assistant engines may be used for any distance to shorten the line by a corresponding amount.

Thus, applying Table L—2 to our example above, we find that the distance over which we may use assistant engines to avoid an addition of one foot to the ruling grade is 0.0195 miles per mile of line. Then, for a saving of 17 feet (50 ft.—33 ft., Fig. 1) we have

$$0.0195 \times 17 \times \frac{105}{100} = 34.8 \text{ miles.}$$

Subtracting the actual distance required, 10 miles, we find that the economy of the low grade is represented by 24.8 miles of assistant engine service, and, by Table L—1

$$24.8 \text{ miles} \times \$4{,}364 = \$108.227,$$

or the same as we obtained above in another way, less a decimal error. The difference in the distance of course is a separate matter, to be subsequently determined. For the purpose of comparing the gradients we must assume the lines to be of the same length as pointed out in the last paper.

Now as a check upon the correctness of all this process, if the reader will take the trouble to turn to Table XX. on page 100, and compute from it the engine mileage requisite to move any given number of cars over each of these two lines, he will find it to be exactly represented by a saving of 25.3 round-trip miles per train over the low-grade line. The slight difference between this distance and the 24.8 miles determined above is an expression of the fact that the balance between the *expense accounts* of the two lines would not be exactly in proportion to the difference in the mileage accounts. As it happens, the nature of this particular problem is such that the difference is quite small. We have thus, after a very roundabout course, checked back on our bench-mark, affording reasonable assurance of correctness throughout, and if at any point in this long discussion we have seemed to be getting far away from a basis of financial fact in the deduction of theoretical formulæ, the reader may feel assured that he can come down to hardpan at any point by a similar process. The writer expresses himself with great confidence on this point, because he has "been there" an innumerable number of times in endeavoring to keep himself right.

We have now finished our theoretical consideration of the subject of gradients, and so far as our ability and foresight has enabled us to do so, have provided a correct and convenient basis for a settlement of all the various problems which arise—or *should* arise—in their adjustment. But, like the wisdom of the famous Bunsby, " the bearing of these observations lies in the application of them," to a far greater extent than in considering the value of other details of alignment, such as curvature and distance, and here we pass beyond the point where a theoretical discussion can be of much value.

We may furnish the means for deciding the comparative value of alternate alignments with the utmost nicety and correctness—or an abler writer may do so for us;—but we cannot formulate rules by which to find those lines, nor to perceive the operating or constructing advantages of a wholly different location, which, nevertheless, may lie upon the surface. This is more or less true, of course, with respect to all the minor details of alignment; but still, so far as curvature and distance and rise and fall are concerned, a man may stumble along from mile to mile and from section to section, doing the best he can in each, and in the end come out not far from right—if he has been guided by proper estimates and not solely by guesswork—and if he do not it is not a very serious matter. But when this method is followed in the all-important question of the adjustment of gradients - as it too frequently is—it is simply ruinous. For the gradients must be adjusted as a *complete whole*, after the most careful consideration of all the broad topographical features of the region to be traversed, and of the conditions of operating economy for the particular traffic in view. The line of lowest grade may not be the cheapest to operate : very frequently it is far from the cheapest. A wholly different location with a wholly different system of gradients may give great operating advantages and at the same time largely reduce the cost of construction. This possibility, however, cannot be discussed in any general form, and we know of no way to so effectually impress it upon the mind of the reader, and at the same time give an excellent practical example of the great economy which may result from the use of assistant engines with gradients skillfully adjusted thereto, as to make a comparison in some detail between the actual and possible lines of two prominent railways, the facts for which happen to be within the writer's knowledge.

THE LOCATION OF THE BUFFALO DIVISION OF THE ERIE RAILWAY.

As a first example of the economy which may result from the use of assistant engines, we propose to consider a possible new location of the Buffalo Division of the Erie Railway, as determined in part by an experimental line which was run some three or four years since, but abandoned as worthless. Circumstances needless to go into led the writer to become thoroughly familiar with the possibilities of the line at the time, but he has since had no reason to remember the facts in detail, nor has he unfortunately, preserved any notes of the line whatever. In respect to details, therefore, he is now obliged to rely solely upon his general recollection of what he then knew to be possible, but at the time he took much interest in the question and can vouch for the substantial correctness of the facts as stated

The general features of the lines which we propose to compare are shown in the accompanying outline map and profiles,† and may be thus described. The present line is about 91 miles long, and for 30 miles of this distance follows a very direct and easy route from Hornellsville on nearly an air line towards Buffalo, as far as the crossing of the Genesee River at the well-known Portage bridge. From this point westward the line makes a wide divergence to the north, in order partly to avoid the high summit on the direct line, descends into and out of the valley of Tonawanda Creek at Attica, and thence takes a nearly direct course for Buffalo, running in all a distance of 61 miles from Portage in order to make an air line distance of from 42 to 45 miles. The line which we now propose to compare with this leaves Portage bridge by an abrupt turn to the southward, passes over the summit ridge between the East Coy Creek and the Genessee River at a slight depression marked A (reaching this point by a short run of $1\frac{1}{2}$ to 2 miles on almost any grade which may prove convenient), and runs thence some 20 or 24 miles through a very practicable valley to the point marked B. In this valley we may secure

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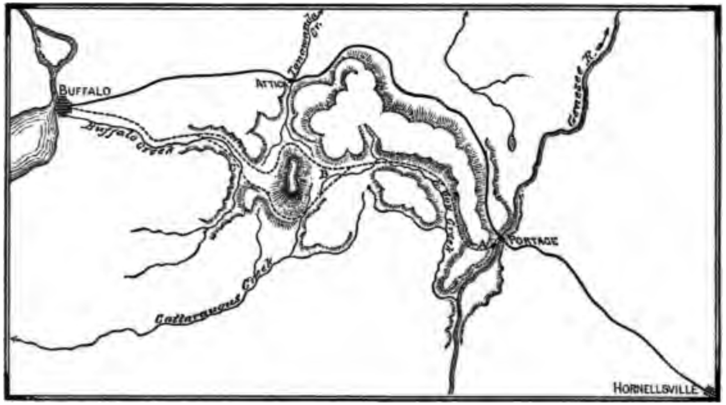
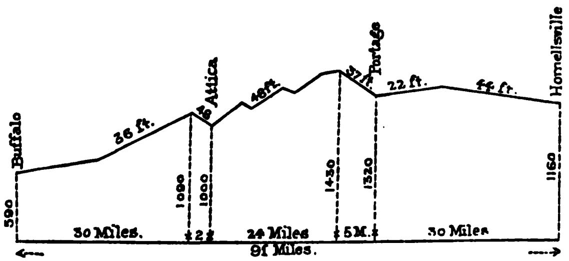
† The map and profile 2 are sketched only from memory and are probably inaccurate in detail. The writer has no large scale map at hand and no exact recollection of the elevations and distances over the proposed line.



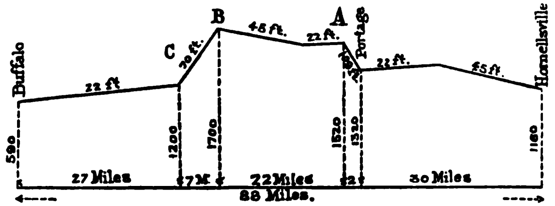
OUTLINE SKETCH OF THE PRESENT LOCATION OF THE BUFFALO DIVISION OF THE ERIE RAILWAY, SHOWING A POSSIBLE IMPROVED LOCATION.



PROFILE I.

Showing a low-summit line with ill-adjusted grades.

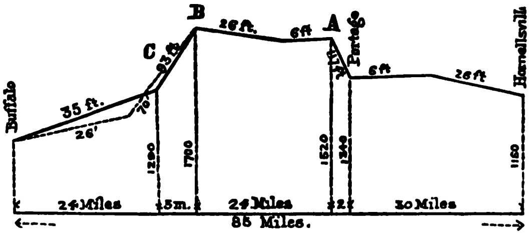
(An outline sketch of the profile of the present line of the Buffalo Division of the Erie Railway. The grades between Portage and Buffalo somewhat exceed those shown for short distances, but may be reduced to the figures given, or below them at slight expense.)



PROFILE 2.

Showing a high-summit line with well-adjusted grades for an unequal freight traffic.

(Profile of the Buffalo Division of the Erie Railway, over a possible new location between Portage and Buffalo.)



PROFILE 3.

Showing the same line as in profile 2, with well-adjusted grades for an unequal freight traffic eastward, coal traffic westward, and uniform passenger traffic.

nearly such gradients as we please and find to be subsequently desirable.

At the point B we are in a series of summit swamps, lying immediately under and not very far from the top of a hill very justly known in the neighborhood as the "backbone of Western New York." It is the highest point in the State west of the Genesee River, and the water runs from it into streams flowing in four different directions. These streams are: first, the Tonawanda Creek, running north, and crossed 10 miles below by the present line of the Erie Railway; second, the East Coy Creek, running east, up which we have just ascended; third, the Cattaraugus Creek, running south; and finally, the Buffalo Creek, which, by a moderately circuitous, route runs directly west to Buffalo. All but the last of these four creeks head together in the swamps at B. The Buffalo Creek, on the contrary, lies in an extraordinarily depressed valley directly west of the summit hill, and runs thence sluggishly towards Buffalo. The outlook into this valley from the summit hill is of the most formidable description, and any regular descent westward is evidently difficult or impossible; but the difficulty which really exists was needlessly exaggerated by the line actually run, for, by an inexcusable oversight, it was run almost over the top of the summit hill and directly down into the valley, showing a profile which would strike terror to the heart of the engineer of an inclined plane.

Nevertheless, these peculiar topographical features offer us great advantages. By swerving our line either to the north or south in the neighborhood of the point marked B, we may, without any difficulty whatever, and with a much shorter line than that actually run, pass through the summit swamps at B into the water-shed of the Cattaraugus or Tonawanda Creeks, and, keeping to the smooth sides of the summit hill on pretty much any grade we please between 50 and 100 feet per mile, pass over the subordinate and much lower summits between those streams and the Buffalo Creek, and running down on the same grade to the bottom of the valley at the point C we may continue on into Buffalo on any grade selected over 20 feet per mile without any considerable difficulty, the line throughout being a cheap line and from 2 to 8 miles shorter than the present line, according to the gradients adopted and other modifying circumstances. Let us see what can be done with this line with well-adjusted grades.

The first question which arises is as to the weight of traffic in each direction. In 1855 this ratio was 10 tons east to 3 tons west, as an average of the whole road. Since that period the disproportion has shown a steady tendency to increase on its rival railways (as will be seen by referring to Table XXI.—A, page 107,) and this tendency will in all probability continue. On the other hand, there is a considerable local tonnage westward towards Buffalo, and a large and probably increasing coal traffic westward; but we will consider later if the gradients cannot be made more favorable than at present for the coal business also, *i. e.*, for an unequal traffic in *both* directions, and assume that the present disproportion in through freight over the Buffalo Division is as 1 to 3. With this disproportion given, we find by Table G, page 110, that the grade going west opposing an equal resistance to 20 feet per mile rising eastwardly is 42 feet, which latter is the grade we may freely use, so far as *through freight only* is concerned. We will increase these gradients, however, to 22 and 45 feet per mile in order to be certain of not assuming the impossible. From the point C to the summit we will assume that a "pusher" is used 20 per cent. heavier on the drivers than the regular through engines. With such a pusher the corresponding grade to 22 feet is, by Table K, page 115, 70 feet, which will therefore answer our purpose as well as a lower grade. From the summit eastward to the point marked A, we may use any grade under 22 feet per mile going east and 45 feet per mile going west, which are far above those actually required for the lightest surface line. In ascending to A from Portage with a pusher similar to that assumed above, the grade of equal resistance to 45 feet is 109 feet (Table K), which we will therefore use. This grade will also be seen in Table G to be the exact equivalent of 70 feet going east, for the given inequality in traffic. Beyond Portage, we have no grades up to or even approaching 22 and 45 feet per mile, except at a few points easily reduced, and we thus pass into Hornellsville at a distance of from 85 to 88 miles from Buffalo. We will say 88 miles.

Let us first determine from the tables we have given the difference in operating value of these two alignments. We have:

In favor of proposed line, 26 feet increase in ruling grade over 22 feet:	
Value, by Table E (p. 92), $\$10,340 \times 26 \times \frac{91}{100} =$	$244,644
Do., 3 miles of distance:	
Value, by Table A (p. 27), $\$3,900 \times 3$	11,700
Total	$256,344
In favor of present line, 9 miles assistant engine service:	
Value, by Table L—1 (p. 120), $\$4,364 \times 9$	39,276
Net balance in favor of proposed line, per daily train	$217,068

As to the number of daily trains, the cost of running which would be affected by this improvement, the writer has no definite information, but we may roughly assume, from the data given in Table J, (subsequent page) that there are 6 passenger, 20 freight and 4 coal trains daily over the Buffalo Division. For passenger and coal business we have not as yet improved the line to any important extent, and we will neglect them altogether. The 20 freight trains over the present line, however, may be readily determined from Table D (page 86) to be equivalent to 20 ÷ 1.625 = 12.3 trains over the lower grades of the proposed line, and we have as the value of the proposed line, for freight business only:

$217,068 × 12.3 = $2,669,936.

Now, if the reader will figure out the present cost of running 20 freight trains over the Buffalo Division, at the low estimate at $1.00 per train mile, he will find it to be $1,183,000. If he then figure out the respective number of cars to a train on these lines, by any standard he chooses to adopt, he will find it to be about as 19 to 31, and he will also find the engine mileage per car moved and returned over the division to be as 9.45 miles to 5.6 miles, a difference of 69 per cent. in favor of the proposed line. From this he may deduce that the yearly saving on the proposed line would be $483,000 if all expenses varied with the engine mileage, but as only 48 per cent. varies therewith, the net yearly saving will be $231,840, which, capitalized at 7 per cent., gives $3,312,000. The excess of about $600,000 in this rough process over the estimate above is simply due to the fact that it confuses the expense account and the mileage account in many minor details, which we cannot go into without retracing our whole argument.

But we have as yet far from exhausted the possibilities of the line proposed. The Erie Railway has a large coal business which requires, for its economical transaction, unequal gradients in the opposite direction to the freight traffic, and it has also a large passenger business, which requires equal gradients each way. In order to adapt the line to these diverse requirements we will readjust the gradients shown on Profile 2, by the aid of Tables G and K, in the manner shown on Profile 3. We will increase the low grade going east from Buffalo from 22 feet per mile to 35 feet per mile; and we will also increase the summit grade from 70 feet to 93 feet per mile. On what we may term the summit level—because it is not a level—we will use grades of 26 feet per mile descending east and 6 feet per mile ascending, and we will increase the grade on the two-mile descent to Portage Bridge from 109 feet per mile to 117 feet per mile. Between Portage and Hornellsville we will by improvements neither very costly nor difficult—reduce the grades to the same as those used on the summit level, viz., 6 and 26 feet.

Now in readjusting these gradients we have violated what is almost an axiom by materially increasing the grades opposed to our heaviest traffic, and yet it may be shown that Profile 3 is decidedly preferable to Profile 2 for freight business alone. Moreover, we have a line on which the ruling grades each way are much over 20 feet per mile, even without considering the heavy summit grades; and yet it may be shown that this line has a higher operating value than if it were reduced to that *summum bonum* of routine engineering, a low summit line with ruling grades of 20 feet per mile each way. We do not say, nor believe, that the grades shown in Profile 3 are in all respects the *best* which can be done in this particular line, but we propose to assume that they are so, and show what an admirable line it is as it stands, in order to illustrate how cheap and excellent lines may be secured through difficult country by a careful adaptation to each other of the special topographical and operating conditions; by adapting our requirements to the ground, and not starting out with a barometer and a lantern to find ground which we may force at great cost to conform to inflexible requirements.

We will first consider the value for freight business of Profile 3, as readjusted; and inasmuch as estimates from our tables will carry conviction to no one but the careful reader of our previous papers, we will hereafter estimate on the basis of the motive power required.

The normal freight train over Profile 3 would consist of 48.3 cars corresponding to a ruling grade of 6 feet per mile according to the standard used in preparing Tables XVII. and XX. (pp. 80 and 100), as against 19.3 cars over the present line with 48 feet maximum grade. We retain the fraction in order to show the exact proportional difference in net load due to the difference in grade.

This train we will run from Buffalo to the summit in two sections of 24 cars and each of these sections again is pushed up the summit grade by a pusher 20 per cent. heavier on drivers than the regular engines. Tables G and K will show these grades to be exactly proportional to this work. From the summit eastward, 56 miles, these two sections are combined into one train and find no opposing grade exceeding 6 feet per mile.

The engine of one of the sections returns light to Buffalo, and we will assume this to be dead loss, although it may be utilized in many ways.

The same train of 48.3 cars returning from Hornellsville is only 3-10 loaded and encounters no heavier gradient at any point than 26 feet per mile (corresponding to 6 feet coming east), except at Portage, where two pushers 20 per cent. heavier on drivers than the regular engines will push the train up the 117 feet grade for two miles to the summit level. Thus we require pushers at only one point each way, first at Portage, where all trains stop at present, and secondly at the foot of the summit grade, which is also a natural stopping place, and where an abandoned road-bed which has been graded and bridged for 20 years connects with the present line of the Erie Railway at Attica and with the Buffalo, New York & Philadelphia Railway at Arcade, 10 miles distant.

The engine mileage required to run a train of 48.3 cars from Buffalo to Hornellsville and return, would be as follows :

	Distance	Mileage, at Work.	Mileage, Returning Light.
Buffalo to Summit (2 sections)..	29 miles.	58 miles.	29 miles.
Pushers on Summit grade......	5 "	10 "	10 "
Summit to Hornellsville..	56 "	56 "	
Hornellsville to Buffalo........	85 "	85 "	
Pushers at Portage Grade	2 "	4 "	4 "
Totals (in all 256 miles).......		213 "	43 "

Equal to 5.34 miles per car moved and returned over the division.
Over Profile 2 (as previously determined) 5.6 miles per car.
" present line " " " 9.45 " " "
" " " reduced to 20 ft. maximum throughout (normal train increased from 19.3 to 32.8 cars) 5.56 miles per car.

We will now consider coal traffic, which by our rough guess is four trains daily. At present these trains encounter a maximum of 48 feet per mile, but by not very expensive improvements this might be reduced to 30 feet per mile, except for two miles of 48-feet grade at Attica, and we will assume the present line to have been thus improved. On this grade a full train will consist of 528 tons, or 29.3 coal cars of 18 tons each, by the same standard which we have used throughout (Table XVII., p.180.) On Profile 3 the maximum grade encountered by coal trains is 26 feet per mile, and the load will be 8 per cent. greater than on 30 feet, or 31.7 cars. But when a coal train has reached the summit on the line shown in Profile 3, we have no necessity to run the coal engine any further. From that point we have a continuous descending grade into Buffalo, and might even run the coal cars down by gravity, but as we have a number of freight engines daily returning light, we may use them to run in coal trains without any cost whatever. To get the empty cars back, we may introduce a special modification of the gradients between Buffalo and the summit, which will enable the regular freight engines to haul them back in sections of half a train, more or less. Sixteen empty coal cars would add the equivalent of 6 loaded cars to a half train of 24 cars, or increase the load 25 per cent., and the corresponding reduction in grade required would be from 35 feet per mile to 26 feet per mile, and from 93 to 75 feet. These reductions are attainable without cost in money or distance, and have not in any manner affected the cost of moving freight eastward nor disturbed the balance of the skeleton outline of gradients shown in Profile 3. We have simply introduced a special modification for a short distance, to accommodate the special requirements of a particular branch of traffic.

The engine mileage to move a coal car from Hornellsville to Buffalo and return would then stand as follows :

Hornellsville to Summit....................	56 miles × 2 =	112 miles.
Portage grade (2 pushers)....................	4 miles × 2 =	8 "
Total for a train of 31.7 cars (3.8 miles per car)..........		120 "

Over the present line, 182 + 4 = 186 miles to move 29.3 cars = 6.4 miles per car.[†]

Now with reference to passenger business over the proposed line: we cannot modify the weight of passenger trains to suit gradients, as we can do with freight trains, but we can modify the weight of passenger engines, and thus effect a nearly equal economy. By the modification we introduced in Profile 3, to accomodate the requirements of the coal traffic, we have also secured a profile for passenger business with balanced maximum grades of 26 feet per mile each way, except on two short planes worked with assistant power. By the present line the maximum is 48 feet per mile, and *whatever* may be the weight of passenger engines found practically advisable over the present line, it may be reduced (by Table XVII.) to 61÷90.8=67.2 per cent. of the present weight, a saving of 33 per cent. We have estimated the value of reducing the weight of through engines to be 45-50 or 90 per cent. of the value of reducing their number, and 90 per cent. of 33 per cent.=29.7 or about 30 per cent. Against this we have 14 miles of assistant engine service in 192, or nearly 7 per cent., leaving a net saving of 23 per cent. in passenger motive power. These assistant engines are attached for short runs of two and five miles at regular stopping places and cause no delay nor inconvenience, while a simple computation will show that the regular freight pushers would have ample power to run passenger trains up the incline at 25 or 30 miles an hour; but the inclines are so short that even if there were some loss of speed it would have no appreciable effect on the average time.

[†] There exists no apparent reason, on the present profile, why coal engines should be run any further than the Attica Summit, inasmuch as the empty coal cars might be hauled back to Attica by the regular freight trains over the 37 feet maximum shown, without limitation of the load which the same engine can haul over the 48 feet gradients from Attica eastward; but we have not assumed this to be done, partly because we believe the coal traffic is not so managed at present, and partly because our design is merely to illustrate a principle, and it is a purely fortuitous accident and not the result of design if the gradients are so arranged at present, inasmuch as such gradients within the maximum limits were evidently used as came most convenient. We have felt that in assuming the present line to be improved as above, we were making sufficient concessions for a fair comparison.

Recapitulating these items we have as the net difference between the present and proposed alignments :

Number and class of trains.	Engine mileage per car round trip.		Percentage of saving in engine mileage.
	Present line.	Proposed line.	
20 freight trains........	9.45	5.34	0.43
4 coal "	6.3	3.8	0.40
6 passenger "	....	....	0.23
Average for 30 trains....................................			0.39

The "line expenses" of the Erie Railway (including all expenses except station, terminal, general and taxes) are very close to 80 cents per train mile, and the corresponding yearly cost for those expenses of operating the present line, assuming 30 trains daily, is 80 cts × 91 miles × 2 × 325 days × 30 trains = $1,419,600.

We have already seen, on page 20, that 5-7 of this amount varies directly with the engine mileage. Hence, we should save of the above amount, 5-7 of 39 per cent. = 28 per cent. yearly = $397,488. This amount, capitalized at 7 per cent., gives $5,678,400 as the difference in operating value in favor of the proposed line. More careful attention to details, or an estimate from our previous tables, would reduce this amount about 15 per cent.; but, on the other hand, we have neglected to consider what is in effect an increase of grade in the present line, arising from unreduced curvature, and some minor sources of error, so the balance is about equal. Nor is this result due to a combination of fortunate circumstances, for we may reverse all the conditions of traffic and obtain a still greater advantage over the present line, although the gradients would be entirely different in detail, and the line, if laid down upon the ground, would undoubtedly require an entire relocation from end to end.

Now this large sum means that injudicious location has *cost* the Erie Railway over $5,000,000, as truly as if the money had been thrown into the sea. For the proposed line is a much cheaper line to build than the present line, and the new line which would now be required could probably be finished to sub-grade throughout for $800,000, or only two years' saving in operating expenses. If this be so, we may stop to consider what is the reason of such marked economy in a line passing over almost the highest point in Western New York. It lies simply in this—that we have *concentrated the resistances.* Every engine while running is kept fully at work, and the gradients are so situated that the greater portion of the work to be done in running either way is concentrated on a portion of the division, and for the remaining distance we have little more need of an engine than to keep the train under control. Therein lies the secret of the economy which may be realized by the skillful use of assistant engines. It is a truth of the first importance that the objection to high gradients is *not* the work which engines have to do on them, but it is the work which they *don't* do, when they are thundering over the track with a light train behind them from end to end of a division, in order to be at hand at a few scattered points where their power is needed, and in the meantime expending their superfluous energy upon the track. But if we may give this additional motive power its work to do once for all, and have done with it, high summits cost very little, and an increase of the rate of grade costs nothing whatever. In very many instances the whole loss is more than repaid by a saving of distance, as in the present case, and there is this further great advantage in thus concentrating resistances for the use of assistant engines, that by so doing we may *cheaply* obtain what is equivalent to a line with very low ruling grades, because at the points of *greatest difficulty* we are independent of the rate of ascent, and in great degree of the elevation attained, and are therefore at liberty to concentrate all our efforts and expenditure on the more tractable portions of the line, where a few feet per mile reduction in grade is of enormous value. In this manner it is in every way practicable to secure lines over high summits and in difficult country which shall approximate closely in operating value to a line on a dead level throughout. For any level line must inevitably be so complicated by curvature that the equivalent straight grade would be from 10 to 20 feet per mile, whereas on many high summit lines worked with assistant power we may, by virtue of the leeway as to rate of descent which our elevation gives us, realize for a considerable portion of the distance the full benefit which we should derive from a straight and level track. Low grades are so frequently complicated by unreduced curvature that few appreciate the great difference which a few feet per mile reduction in very low gradients makes in the net load of engines. For example, if Profile 3 be examined, it will be seen that the *limiting* gradients—the ones to which we have been obliged to adjust all the others for fear of exceeding the topographical possibilities- are the very lowest of them all, viz., those on the summit level and east of Portage. Now *if* we can reduce these low grades from 6 and 26 feet to level and 13 feet per mile, we shall effect an enormous economy in operating expenses, because we could probably without much difficulty reduce the other and higher gradients to correspond therewith, and the regular load of engines over the whole line would be increased by the difference in the loads which it can regularly haul on grades of 6 feet per mile and level, which is 190 ÷ 153 = nearly 25 per cent. greater. In order to effect a similar saving in operating expenses on the present line with 48 feet maximum grades, we should have to reduce these grades by 13 feet per mile, and as this reduction would have to be made at the most difficult points on the line, it would probably be attended with many fold the expense of reducing our lighter gradients 5 or 6 feet per mile. Therefore, if we can reduce those lower grades without excessive cost, there is the place for unhesitating expenditure, leaving the heavier gradients on the short sections of rugged and difficult country to take care of themselves. We may thus obtain out of the high-summit Buffalo Division a line closely approximating in operative economy to the low grade Susquehanna Division, which has ruling grades of 6 feet per mile indeed, but so complicated by unavoidable curvature that a locomotive which would haul 48.3 cars over the straight 6 feet grades shown in Profile 3 would haul less than 40 cars over the Susquehanna Division, so that to move one car 85 miles and return would take 170÷40 =4.25 engine miles. On the other hand, if we can reduce the 6 feet grades of Profile 3, through a few miles of easy country, to a level, reduced to a descending grade on curves, we shall be able to increase our normal train from 48.3 cars to the full level load of 60 cars. The mileage of engines, however, remains the same as before, so that the engine mileage per car round trip of 85 miles would be only 256÷60 =4.27 miles, as against 4.25 miles over an equal distance of the Susquehanna Division.

Now if this ultimate economy be not attainable on the particular line which we have been considering, it is in many instances, and more attention should be paid in location to these possibilities of economy. It is time that these high elevations which we cannot avoid altogether should be put into the treadmill and made to do duty. It is possible to do so, and the possibility should be kept in view on *all* lines through difficult country. For that country is rough indeed through which a line cheap to build and economical to operate cannot be obtained by looking for it, if, *first*, we determine exactly what is required by special investigation of each case, and, *secondly*, seek for no more than that, nor spend a dollar to obtain it. But by seeking *for what we do not require* we shall often destroy possibilities of greater advantage than if we found what we are looking for, and if we defy the obstacles of nature by forcing them to conform throughout to the Procrustean standard of a uniform ruling gradient, we enormously increase the cost of construction, and in the end find that we have a far more costly line to operate than if we had "stooped to conquer" by boldly conforming to the topographical conditions and then skillfully forcing them to serve our purpose. We may thus obtain many of the advantages of the gravity railroad, and in order to do so the true policy in very many instances in difficult country is to make boldly for the "meeting of the waters" at the summit, and by thus concentrating our resistances, have *most* of our line on very favorable grades,—instead of zig-zagging up and down and from side to side in search of a costly approximation to the impossible, viz., a line of *uniform* low grade through a hilly or mountainous country. Such a line never has been found, and it is safe to say it never will be.

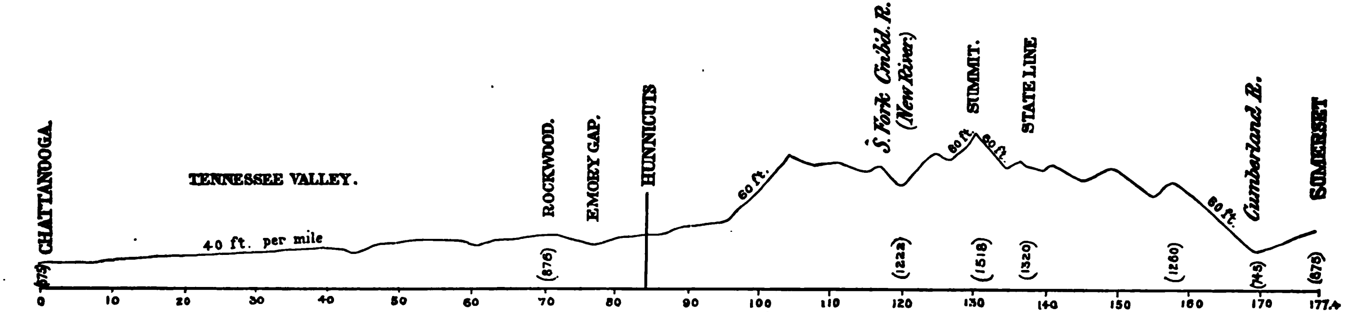
We know of no more forcible illustration of the correctness of this principle than may be found in the alignment of a great railway now building, the moral from which is so important that we feel bound to consider it in some detail in the following paper. It furnishes a remarkable example of the art "how not to do it" with the utmost care, if we keep but one end in view instead of giving full consideration to all the possibilities. This is also true of the line which we have just been considering. The engineer who made the survey started out with the definite purpose of finding a line with 20 feet maximum grades. In order to do it he made a detour at the very beginning which sacrificed eight miles of distance, in order to reach the point marked A on the map above; and yet even this process, continued throughout the survey, could not produce a line with 20 feet maximum grades, although it *did* show a very absurd and worthless line. Consequently this territory stands reported as wholly worthless for railway purposes, with maps and profiles to prove it abundantly, and yet a better line than if he had actually obtained his 20 feet maximum without sacrifice of distance was there before him, if he had but looked for it. In making these remarks the writer would be very unwilling to wound the feelings of any one, and still more to appear to set himself up as a master of the art of location; but he has used this line because an actual instance is so much more convincing and effective than an imaginary case, and if the facts be questioned, he can only add that he is at all times ready to substantiate them by running the line without money or price, solely for the satisfaction of testing the correctness of his own judgment and seeing exactly what may be done. He hopes at least that—if he chance to have an attentive reader among the younger members of the profession—he has convinced him that something more is required of a good locating engineer than the ability to run in a curve and fit it nicely to the ground. This is a rare and valuable accomplishment, but in comparison with the value of a skillfully adjusted *system* of gradients, it does not much matter whether the minor details are skillfully adjusted or not.

THE LOCATION OF THE CINCINNATI SOUTHERN RAILWAY, BETWEEN SOMERSET AND CHATTANOOGA.

As a second illustration of the great advantages which may often be realized by using assistant engines on well adjusted grades, we propose to make a comparison between the adopted line of the southern half of the Cincinnati Southern Railway between Somerset and Chattanooga 177.4 miles and a rejected route which passes over the highest summit and has nominally the highest ruling grades of any one of the 26 different routes given in the "Preliminary Report on Surveys." In the view of the writer, this route is not only by far the cheapest of them all to build, but it is also by far the cheapest of them all to operate. In reaching this conclusion he relies only on the published maps, profiles and reports of the railway, and has the advantage of no personal knowledge of the facts whatever beyond this, if we except that given by a short trip over a portion of the present line. The Cincinnati Southern Railway, however, has set such an excellent example to other railways in the care with which the fullest details of its location and construction have been recorded and preserved, that he can hardly be accused of evolving a location out of his inner consciousness, and if he has erred in any detail he will take sincere pleasure in acknowledging and correcting it; but he fears that, after making all allowance for any such, no candid reader will question the substantial justice of his position.

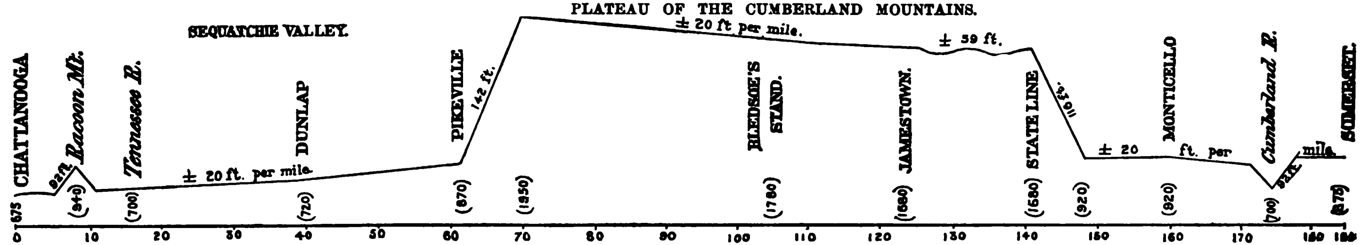
He will only add further that he has no manner of knowledge as to who may be mainly responsible for the adoption of the present line and feels the greatest unwillingness to reflect upon the work of any one, but he feels bound to use so forcible an illustration of the principles which he has endeavored to inculcate in the interest of professional knowledge.

The present line of the Cincinnati Southern Railway, as may be seen on the accompanying map, crosses the Tennessee River immediately out of Chattanooga, and follows up its valley to Emory Gap, 76 miles. On most of this distance the work is comparatively light and the ruling grades are 40 feet per mile, increased by 4° curves. From Emory Gap to Somerset, Ky., 101 miles, the line follows defiles or ridges of the Cumberland Mountains and is throughout of the most difficult and costly character. It is, beyond doubt, the heaviest consecutive 100 miles of railway in the United States, and the ruling grades



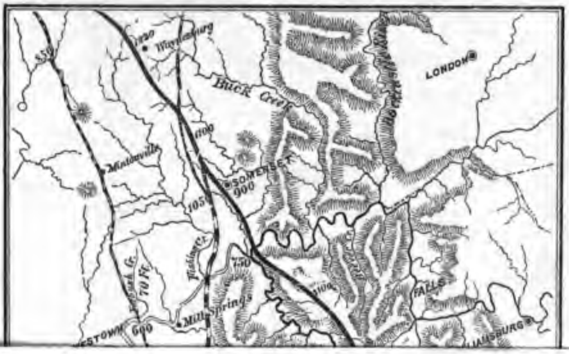
PROFILE 4.

Outline sketch of the profile of the adopted line of the Cincinnati Southern Railway between Somerset and Chattanooga, showing a low-summit line of costly construction, with gradients comparatively ill adapted for operative economy. Note.—This profile has no pretention to correctness in detail. Operating Division 3, from Somerset to Hunnicuts, has about 28 miles each way on the maximum grade of 60 feet per mile. Operating Division 4, from Hunnicuts to Chattanooga, has about 17 miles each way of 40 feet grades, probably all in short sections.



PROFILE 5.

Outline sketch of the profile of the "Sequatchie Valley Line" for the Cincinnati Southern Railway between Somerset and Chattanooga, as deduced from the preliminary surveys, showing a high-summit line of cheap construction with gradients well adapted for operative economy, by the aid of assistant engines.


Waynesburg
LONDON
Buck Creek
1100
Mintonville
SOMERSET
900
1050
750
Fishing Cr.
70 Ft.
Mill Springs
600
FALLS
1100

very smooth and level, with the lightest kind of surface work the whole length of the valley (46 miles from the Tennessee River crossing). A few lateral streams cross the line, but small embankments and bridges will raise it above them. The Sequatchie River requires a bridge 150 feet in length.

"The valley is well settled, and said to contain iron ore in great abundance. Coal is also abundant on both sides of the valley, and the timber is abundant and good. An extension of a few miles would give a direct connection with the Memphis & Charleston Railroad, saving about 30 miles of haul on all business from the southwest."

From the report of the Nashville & Chattanooga Railroad for the present year we learn that such an extension is now being made by that road to reach the rich mineral deposits of this valley. and that outcroppings of bituminous coal in veins of 7 to 10 feet, and of hematite iron ore in veins of 4 to 8 feet, are found in close proximity. Those familiar with mining will appreciate the extraordinary character of such deposits, but in this much-favored region it may be equaled on the other side of the mountain, along the adopted line.

The average fall of this valley is under 5 feet per mile, but we will assume that 20-feet grades each way will be required, with 8,000 yards per mile of earthwork, and only half of the bridging on the parallel Division G of the present line, as the valley is evidently much smoother and less cut up by streams than the Tennessee valley on the other side of the mountain. This would make the cost of grading and bridges per mile $2,650. We will say $3,000.

Thus we reach Pikeville, at the head of the valley, and begin the ascent to the Plateau of the Cumberland Mountains. This ascent was made on the preliminary survey with an unbroken grade of 111 feet per mile for 9.6 miles; total ascent, 1,066 feet. Of the line we have the following description:

"The work on the ascent from the Sequatchie Valley is the heaviest we have anywhere encountered. Every effort was made to make the best of this line, but the face of the mountain is so broken up with rocks, cliffs and gorges that it is difficult to get a line which may be called practicable. Tunnels, trestles and heavy cliff work are continually required. * * Daddy's Creek runs very close to the head of the Sequatchie Valley, and by commencing about the high-water mark of this stream and tunneling into the head of the valley, and then tunneling a tongue of land called Brown's Gap, and then crossing four very large and deep gorges, with similar work beyond this point to that on the other route, the descent may be made with a grade of 105 feet for seven miles and easier grades for the rest of the descent, the total fall being about 900 feet."

Now this is discouraging enough, but careful reading will show that all this costly work is encountered in seeking after two wholly unnecessary ends. The first of these is to reduce the rate of ascent to the *lowest possible limit;* but if we operate the incline with assistant engines the rate of ascent is wholly a matter of indifference within wide limits, and we could not ask a more forcible instance of the great economy in construction which results from their judicious use.

In evidence of the slight importance of the *rate* of grades on inclines worked with assistant engines, we add the following table:

TABLE XXIV.

Showing the engine ton-mileage required to move one ton of net load 100 *miles on a level, except for a rise of* 2.400 *feet on different grades, worked with assistant engines. According to the average daily experience of American Railways, as determined from Table* XVII.

Rate of grade on incline. Ft. p'r mile	Length of incline. Miles.	Length of level track. Miles.	Engine ton-mileage per ton of net load moved 100 miles.		
			While on incline.	While on level track.	Total.
24	100	0	1.056	0.0	1.056
30	60	40	0.862	0.210	1.072
80	30	70	0.760	0.369	1.129
100	24	76	0.755	0.400	1.155
120	20	80	0.766	0.421	1. 87
150	16	84	0.803	0.442	1.245
200	12	88	0.900	0 463	1.363

It will be seen that the rate of incline has an inconsiderable influence on the motive power required, and the thoughtful reader will perceive why this should be so and yet that high *ruling* grades, for through engines, should be a very costly luxury. If we keep two "Consolidation" pushers at work on this incline, the motive power is increased five times, and the grade corresponding to 20 feet for one engine will then (by Table XVII.) be 145 feet per mile, and this grade is in no appreciable respect more costly or objectionable than a grade of 92 feet per mile, worked by one pusher.

The second unnecessary end referred to lay in the attempt to make the whole surface of the earth fit a 6° curve. Now we certainly have no right to introduce sharper curvature on one line than the other, *under the same circumstances,* and then compare the two, however much we might question the propriety of the standard adopted; but we *have* a right to assume that if this survey had been conducted with reference to the possibility of properly adapting the line to assistant power (as it evidently was not), the locating engineer would have investigated the subject, as we shall do in the following paper, and discovered—if it was not already known to him—that 10° curves were no more objectionable to trains worked with such pushers than 6° curves to the same train with only one engine. This is more especially true if in both cases the grades were heavily and amply reduced for curvature, but it is very nearly true if neither is. On the present line the maximum grade was not reduced on curves, but it will be evident that with 142 feet grade and 10° curves on this short incline, we might easily do this and at the same time reduce the cost of construction to very reasonable limits, say $40,000 per mile. The heaviest 40 miles of the present line, very heavy throughout, averaged $60,000 per mile, but we think this estimate is fair. The reader has all the facts before him which the writer has, and can judge for himself.

We are now on the PLATEAU OF THE CUMBERLAND MOUNTAINS, on the highest point touched by 1,500 miles of surveys for 26 different routes, viz., 2,000 feet above the sea, and 500 feet higher than the highest point of the present line. This plateau is a peculiar topographical feature, and is thus described:

> "It is a vast plateau (about 25 miles wide by 80 miles long) elevated above the adjacent country on either side by from 500 to 1,200 feet. While maintaining in general the character of a table-land, it has large regions cut up by deep drainage, and other spaces on which rise great masses of mountains still more elevated. These two latter classes of plateau are almost entirely impracticable for railway purposes, but in other parts the table-land affords good routes for considerable distances. The ridges between the streams are often quite level, and the upper part of the streams are flat until they begin to cut through the heavy sandstones which form high cliffs along the larger streams and bound the spurs of the entire mountain. The entire mountain is a coal field, the stratification being nearly horizontal."

On this plateau we follow the dividing ridge to Jamestown, 52 miles. Of the last 18 miles of this distance we are told:

"The plateau is smooth, and the line down the divide is straight and level, with light work."

Of the remaining 34 miles of this distance:

> "The line actually run (to pass off from the plateau to the southeast through Crab Orchard Gap) was not favorable. * * * This can, however, be avoided by following the main divide south of Bledsoe's Stand, which would take the line four

miles west of Crossville, and make the distance from Bledsoe's to the head of the Sequatchie Valley, 32.9 miles. This would probably make the route similar to the light ridge work between Bledsoe's and Jamestown."

This is the line shown on the map and in Profile 5, and we assume from this description that 20 feet grades may be easily obtained on this distance with 15,000 yards of earthwork per mile, and possibly one or two trestles, but with no bridges or even culverts of any importance. At 15 cents per yard (about the average price on the present line) this gives $2,250 per mile to subgrade, but we will say $3,000. We are here parallel with, about 25 miles west of and from 500 to 1,000 feet higher than, what is probably the costliest line (measured by labor performed) in the United States.

North of Jamestown the line follows a narrower dividing ridge to the State line, 18⅛ miles by survey, 12 miles in an air line. Of this stretch we are only told that it has "considerable heavy rock cutting," and nothing is said about grades. We will therefore assume that on this stretch and thence northward down the Cumberland Mountain (24 miles) we shall be obliged to use a 20-ton assistant engine and use the corresponding gradient (by Table K), 59 feet per mile. With these grades it would appear to be a fair estimate that this 18 miles will cost about two-thirds as much per mile as the parallel Division E, less the cost of bridging and tunnels, or about $16,000 ($15,700) per mile. Division E has nine tunnels averaging 820 feet long, and the above sum is sufficient at the average prices for 20,000 yards of rock excavation per mile.

At the State line we descend from the plateau (760 feet) with "a grade of 80 feet per mile for nine miles. The work is extremely heavy, embracing several tunnels and high trestles, and a large amount of rock excavation. The alignment is fair."

Here we have an exact parallel to the ascent before considered, and need not go over the ground again. With one heavy pusher in addition to the 20-ton assistant from Jamestown, we have four times the usual motive power on the 20-feet through grades. The equivalent grade is 120 feet per mile, the equivalent curve is 8° or 9° at least, and with them we can shorten the descent at least one mile, and probably decrease the cost per mile to about two-thirds of the average cost of Division E, including tunnels, bridges and masonry, or about

$30,000 per mile. In evidence of this we may add that seven and a half per cent. of Division E is through tunnels or on viaducts.

From the foot of the Cumberland Mountains we pass, without difficulty, to Monticello, nine miles distant by survey. and on the same elevation. We increase this distance, however, two miles, in order to avoid a tunnel through a spur of the mountain and reduce grades to 20 feet. As there are no streams to cross, and we are told that on the preliminary line "the work is light, with fair alignment," and the region around Monticello is described as a "smooth table land," the possibility of doing so would seem to be a fair assumption, if we allow 40,000 yards of earth-work per mile, or its equivalent in other work, which would make the cost $6,000 per mile.

At Monticello we are obliged to abandon the natural continuation of the Sequatchie line northward (shown on the map by the light dotted line), in order to connect with the present line at Somerset for comparative purposes. In order to do this we will piece out our line with a section from another abandoned line, which runs northeasterly from Monticello, and crossing the adopted line near Somerset, continues on to the eastward. This section is described as follows:

> "The distance from Somerset to Monticello is 24 miles. The heavy work on this distance is confined to seven miles of 76-feet grades on the cliffs of the Cumberland and the bridge over that stream [described as 800 feet long and 90 feet high as against 1,200 feet long and 150 feet high by the adopted line]. On the remainder of the distance the work is very light, the grades easy and the alignment good. It is an old-settled limestone table-land and has some fine-looking farms. The edge of the coal field lies just east of the line, and good coal can be procured by short branch lines. Iron ore is also found here and was worked to some extent some years ago."

It would seem that $3,000 per mile (20,000 yards of earth) was a sufficient estimate for 17 miles of this line, and that grades of 20 feet per mile would be easily attainable. On the remaining seven miles at the Cumberland River crossing we will use 92-feet grades, as in crossing the Raccoon Mountain, instead of 76 feet, reducing the cost of construction to about $15,000 per mile, that amount being sufficient to make a solid rock cut 10 feet deep and half a mile long. In this estimate we do not include the Cumberland River bridge, which would be reduced by such grades to about half the cost of the present crossing, or about $100,000.

Summarizing the estimated cost of constructing this line, we have :

Somerset to Monticello, 24 m..	Cumberland River crossing,	7 miles	@ $15,000	$105,000
	“ “ bridge,			100,000
	Monticello Plateau,	17 “	@ 3,000	51,000
Monticello to Pl't'u C'm'd Mt 19 m....	“ to ft. of C'm'b'd Mt.,	11 “	@ 6,000	66,000
	Ascent to C'm'b'd' Plateau,	8 “	@ 30,000	240,000
Plateau of C'mb'r'nd Mts., 70 m	State Line to Jamestown,	18 “	@ 16,000	288,000
	Jamestown to head of Seq. Valley,	52 “	@ 3,000	156,000
Seq. Valley, 54 m......	Descent from C'm'b'd Plat.,	8 “	@ 40,000	320,000
	Pikeville to Tennessee R.,	46 “	@ 3,000	138,000
Tenn. R. to Chat. 17 m	Tennessee River bridge (as on present line)			300,000
	From “ “ to Chatt.,	16 miles	@ $20,000	320,000
Totals, 184 miles				$2,084,000

Out of the whole distance of 184 miles, 46 + 52 + 17 = 115 miles, is described as work of the lightest character, 11 miles as light, 41 miles as moderate and only 18 miles (which we assume to be reduced by higher grades to 16 miles) as excessively heavy, with the alignment described in the report, so that the writer cannot but regard this as a fair and more than ample estimate, but he admits that he may be influenced by his own prepossessions, and he will therefore increase the above estimate as follows :

Total previously determined..............................	$2,084,000
Add 10 per cent. for any under-estimate at special points..	208,400
Total..	$2,292,400
Add 10 per cent. for any general tendency to under-valuation..	229,240
Total..	$2,521,640
Add 10 per cent. for any other sources of error............	252,164
Total, showing estimated contract price for grading, bridging and masonry..............................	$2,773,804
Actual and estimated contract price of the adopted line, for grading bridges and masonry........................	7,124,550
Balance, showing estimated saving in cost of construction in favor of the proposed line............	$4,350,746

We may also tabulate the following comparative details:

	Adopted Line.	*Proposed Line.*
Length..........	177.4 miles	184 miles.
Tunnels.		
Number........	25	Probably no tunnels, with grades proposed. The survey indicates several on each of the mountain grades and two others.
Length.........	22,081 feet 4.2 miles	
Iron Bridges. (Exclusive of Cum'd and Ten. R.) No. of spans.	58	1 (Sequatchie River). 150 ft. long, all other requirements believed to be included below.
Total length....	4,357 feet 0.82 miles	
Iron Viaducts.		
Number........	27	1, at Cumberland River, 400 feet, and possibly several others on the mountain grades.
Length.........	10,821 feet 1.95 miles	
Wooden Bridges.		
No. of spans....	26	26
Length.........	611 feet	611 feet
Wooden Trestles.	1,100 feet	1,100 feet
Ruling Grades.		
NOMINAL........	Operating Div. 3, 60 ft. per m. " " 4, 40 " " "	One operating division 142 ft. per m. 120 ft. per m. 92 ft. per m. 59 ft. per m.
ACTUAL.........	" " 3, >75 " " " " " 4, >50 " " "	20 feet per mile.

In explanation of what are given as the "actual" ruling grades, we need only add that a true ruling grade is one which *fixes the weight of trains.* Now a 60-feet grade increased by 6° curves is not a *ruling* grade, nor is it even a maximum grade in the meaning which that term conveys, because the grades on all tangents *might as well be* increased to 75 feet per mile and in fact considerably more, before they will exercise as great a limiting effect on trains as will a 60-feet grade on a 6° curve, and, however common the fault may be, it is excessively bad engineering not to do so. We cannot stop now to justify this position, for we shall do so in the following paper; but we have considerably understated the *true* limiting effect of curvature on grades. On the other hand, a location adapted to the use of assistant engines offers abundant facility for reducing grades heavily for curvature at the points of greatest resistance, by the wide lee way which we have at such points as to the rate of grade, while the few and light curves on the higher portion of the line may, in this instance at least, be amply reduced without appreciable cost.

We can now proceed to consider the comparative OPERATING VALUE of the proposed line. Its broad features may be stated as follows:

1st. It constitutes in effect a single operating division, 184 miles long, over which the same engine will take the same train through without change, changing crews at any convenient point on the mountain. This makes a well-adjusted day's run under the long-trip system.

2d. At each terminus of this division a powerful pusher is required for three miles. It would probably be more economical to make this a kind of yard service at the Cumberland River, and let that be the terminus of the division; and at the southern end it might possibly be better to locate the first 16 miles out of Chattanooga with reference to operating it as a separate division, as a large trade from the Southwest would doubtless be received there which would never pass through Chattanooga.

3d. For about eight miles each way, at a single point in the middle of the run, powerful pushers would be required. These engines would make six or seven trips daily.

4th. A 20-ton assistant engine would *probably* be required between Jamestown and the State line, and if so we have assumed that this engine will also descend to the foot of the mountain, to push up returning trains.

Summing up the engine mileage required to run a train over the division, we have:

Through engines, 20 tons.	Going North.	Going South.
Chattanooga & Somerset	184	184
Jamestown, foot of Cumberland Mt	26	26
Totals	210	210
Pushers, 40 tons:		
At Chattanooga	3 × 2 = 6	3 × 2 = 6
" Somerset	3 × 2 = 6	3 × 2 = 6
On Cumberland Mountain	8 × 2 × 2 = 32	8 × 2 = 16
Totals	44	28

Estimating the mileage of the heavy pushers as being 50 per cent. more costly than that of the light through engines, we have as the total mileage required to move a train of 20.76 cars each way:

Through engines	420 miles.
Pushers, 72 miles, increased 50 per cent	108 "
Total engine mileage per train	528 "

Equal to a total engine mileage per car moved and returned over the division of 25.43 miles.

We will now compare with this the engine mileage required on the adopted line. Operating Division 4 is 84.4 miles long, with ruling grades of 40 feet nominal, and 50 feet actual, and Operating Division 3 is 93 miles long, with ruling grades of 60 feet nominal and 75 feet actual. On these grades a 20-ton engine will, according to the same standard by which we determined the net load on the proposed line (Table XVII., page 80), haul only 11.82 and 8.42 cars respectively.[*] Heavier engines will probably be used, but whatever advantage this may give is equally open to both lines, and, even if it were not so, we have already shown that the cost of increasing the weight of the same pattern of through engine is nearly as costly as is increasing their number. This is a very different matter from the relative cost of a heavy eight-driver pusher running only on a short incline and where speed may be decreased without appreciable loss. For the cost of 20 minutes' delay is not 1-60 of 20 hours delay, nor 1-600 part.

Estimating then the comparative engine mileage per car hauled required over the present line, we have:

On Division 3, 84.4×2=168.8 miles run by engine to move 11.82 cars	=14.28	miles	per	car.
On Division 4, 93×2=186.0 miles run by engine to move 8.46 cars	=22.00	"	"	"
Total between Somerset and Chattanooga	36.28	"	"	"
" previously determined for proposed line.	25.43	"	"	"
Saving in engine mileage per car, on proposed line	10 85	"	"	"

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[*] Table XVII. was made up for a rolling friction of 10 lbs. per ton which was deduced from loads hauled over grades complicated with curvature. We use it now simply as a matter of convenience, and because, as we have already pointed out, the *difference* in the engine mileage per car, and hence the difference in operating value, remains precisely the same whether the car friction be taken at 1 lb., or 10 lbs., or 100 lbs. per ton, although the cost of operating *each* line is very greatly affected thereby. The above loads, however, are but little below the average loads in the daily routine of business, as we might show from statistics, except that it is of no present importance.

a saving of almost exactly 30 per cent. of the engine mileage. If we estimate the cost of a train mile at $1.25 (less than on most of its rivals), we have seen, on page 91, that 48 per cent. of this sum, or 60 cents, may be assumed to vary directly with the engine tonnage. Then 30 per cent. of 60 cents = 18 cents per train mile require over the *present* line, as the saving in operating expenses over the proposed line. This is equal to $0.18 × 177.4 × 2 = $63.86 as the saving per train round trip, and this sum × 325 gives $20,756 as the yearly saving in favor of the proposed line, per daily train required over the present line.

As to the probable number of trains over the present line, it is wholly a matter of conjecture; but the Cincinnati Southern doubtless anticipates that in the near future it will have a business closely approximating to that now enjoyed by the Nashville & Chattanooga and the Louisville & Nashville railroads, which is over 16 trains daily. A business of 14 trains daily over the adopted line would show a yearly saving in operating expenses of $20,756 × 14 = $290,584 in favor of the proposed line, and capitalizing this sum at 7 per cent. we have as the difference in operating value in favor of the proposed line, $4,151,200.

In this estimate we have neglected several minor considerations, both pro and con, which we may briefly define. Those in favor of the proposed line are:

1*st*. A saving in cost of curvature. On one division of the present line there are 9,670° ± of curvature (104° per mile); and on the other, 3,270° ± (39° per mile). We may roughly estimate the curvature on the proposed line at 30° per mile for 156 miles, giving 4,680°, and at 120° per mile on the remaining 28 miles, giving 3,360°. Without going through the steps of the process, if the reader will increase these amounts in proportion to the engine tonnage passing over them, as suggested in the last two papers, he will find that the resulting difference represents a capitalized sum of about $275,000, at $3.48 × 1.25 per degree. There is also an inconsiderable advantage in the cost of rise and fall on the proposed line, which we pass over entirely. On the present line there are about 2,086 + 827 = 2,913 feet of rise and fall. On the proposed line the *necessary* amount will be seen to be only 1,630 feet. After reasonable increase. the difference between the two lines for this item is some $12.500.

2d. An exaggeration of the value of the distance saved by the present line. In estimating on the basis of the engine mileage, the relative value of the two lines, so far as affected by distances, is necessarily assumed to be directly as the measured lengths, or as 184 to 177.4. The true ratio, as we have pointed out in considering the value of distance (page 389) is as 180.7 to 177.4. This error thus amounts to $\frac{3.3}{184}$ of $4,151,200, or about $75,000.

3d. A saving in the cost of maintenance of way, due, not to any difference in alignment or engine tonnage, but to a difference in topographical conditions. If we balance 110 miles of the two lines against each other as approximately equal, we have 70 miles of light work with hardly a box-drain on it on the top of a sandstone ridge as against 70 miles of exceedingly heavy work. Every trackman will appreciate the importance of this difference. The writer could hardly estimate it at less than 20 per cent., or say 7 cents per train mile, which would amount to $637,000.

4th. A saving in the capital invested in engines. Including the saving by consolidation of divisions this would be at least one-half, and allowing 80 engines at $8,000 each as the equipment of the present line, this would amount to $320,000.

Per contra, we have neglected the following considerations which operate against the proposed line:

1st. It is much more difficult to make a good connection with Knoxville and the important trade centering there. This is certainly a very grave disadvantage, although balanced in great degree by better facilities for reaching the more important trade of the West and Southwest. The difference in the cost of a branch to Knoxville, however, would be fully covered by $500,000, and when once built we may consider the operating advantages as equalized.

2d. We have neglected the loss arising from assistant engines standing idle in the yard. We will grant that these engines would average only 6-10 of a day's work, while having steam up all the time—a very excessive assumption. The cost will then be the same, as we have seen on page 120, as if the mileage were 1-6 greater without this loss. This will be found to decrease the difference in operating value by about 8 per cent., or $332,000.

Summing up these various minor items, we find we have a net balance of $1,307,000 less $832,000, $475,000 in favor of the proposed line. We may now make a final summary as follows:

Difference in cost of construction, in favor of proposed line	$4,350,746
Difference in operating value, in favor of proposed line, for a business corresponding to that now transacted on railways between Chattanooga and Louisville	4,151,200
Minor items, balance in favor of proposed line	475,000
Total estimated difference in value, in favor of proposed line	$8,976,946

This is a vast sum, almost beyond belief, and we will therefore grant that unconscious prepossession has led the writer to exaggerate the various estimated advantages of the proposed line by as much as 100 per cent., in spite of his earnest endeavor to be more than fair. The difference is still sufficient for the moral which he designed to draw, and he has no other purpose in writing the present paper. It is needless to say that he personally believes the error to be in the other direction, *if* the business of the Cincinnati Southern Railway does in fact reach the proportions which its projectors have evidently anticipated and built their railway to transact. Moreover, we have as yet far from exhausted the possibilities, and one of these is so important that we must briefly suggest it. A glance at Profile 5 will show that there is a gradual fall on low grades from the summit northward. Now *if* it were possible to locate this with a level maximum going north, and eventually build from 60 to 90 miles of independent return track on the lighter portions of the line, with a level maximum going south—by adding a few miles run of assistant engines, mainly or entirely at their regular stations—we should realize all of the advantages of a double track, and at the same time approximate closely to the ultimate limit of economy in transportation. Such an alignment would be a method of utilizing the advantage of the gravity railroad without the disadvantage of stationary power, and the topographical conditions are in many respects singularly favorable. It is easier to suggest this than to accomplish it, but it is also easier to deny or forget the possibility than to look for it.

Another possibility of much interest would have been the use of the *central rail system* in ascending to the plateau, or even inclined planes with stationary power. The topographical conditions are peculiarly favorable for either of these expedients, and although inclined planes have passed out of use in many cases, it does not follow that in other cases, with well-adjusted grades, they may not be exceedingly advantageous. So also with the central rail system, it is not at all necessary that a road should use this system throughout to reap its advantages, simply because most of them do so, and sound engineering should give all these possibilities the most careful investigation before rejecting such a line as this on account of a few miles of abrupt ascent. In these remarks it is by no means our wish to suggest that the engineering administration of the Cincinnati Southern Railway is especially open to criticism. On the contrary, it has been in very many respects especially admirable from the very beginning. Multitudes of other railways would furnish as striking instances of erroneous location, if the facts were known in the same detail, and among these we may mention three on which the loss has been nearly or quite as great as in the instance we have been considering, viz.: the Chesapeake & Ohio, the New York & Oswego Midland and the Blue Ridge Railroad, and from precisely the same cause, viz.: the neglect of possible advantages from the use of assistant engines in the vain attempt to get a line of *uniform low grade* through a mountainous country. This error is one of the gravest character and it is continually committed; the great cause of it being that constructing engineers, as a rule, give no sufficient and comprehensive attention to the true and exact conditions of operative economy. When the road is finished, the "Chief Engineer" receives his modest stipend and departs, and the manager who succeeds him, rarely knowing anything about gradients or location, takes the line for granted as he finds it, and does not know, nor will he probably believe, that anything better is possible. And so, between these two stools, the intricate and difficult science of railway location has fallen to the ground, until it is hardly even *considered* important or intricate—and in no one respect has this process resulted in more unfortunate error than in the location of lines through mountainous and difficult country. If the writer were to lay down a broad general rule for sound location in such localities, it would be this : Follow the easiest routes on the lowest grades possible for the longest distances possible; and then pass over the intervening distances on such grades as are then found necessary, by the aid of assistant engines. *On this system the rate of the high grades and even the altitude of the summits matters little or nothing*, within wide limits, and it is economical both in cost of construction and in operating expenses; although the full advantages of the system can be realized only in the hands of that exceedingly rare bird, a good engineer and a good railway manager in one and the same man; for it requires the nicest adjustment to each other of the alignment, the gradients, the locomotive power, and the daily management of traffic. It is therefore perhaps an unattainable desideratum, but no more forcible example of the correctness of the principle could be desired than is probably furnished by an alternate location for Operating Division 3 of the present line of the Cincinnati Southern Railway. The writer hesitates to use it, because no line has been run over it, but he has some personal knowledge of what would ordinarily be the most difficult part of this line, and if the indications there given are not deceptive, he does not hesitate to say that a better line than that adopted lies almost within sight of it for its whole length. This line would be as follows: Diverging from the present line on the summit between the Emory River and the South Fork of the Cumberland, to descend as speedily as possible on any convenient grade into the valley of Wolf Creek and the Cumberland River. If, as is usually the case, the valley widens and becomes more practicable as it descends, we have then a light and low grade line as far as the Cumberland River, the only difficulty being to keep above high-water mark. The average fall is only about eight feet per mile, and 20-feet grades might very probably be obtained over the whole distance of 85 miles, except for say 10 miles each way of any grade under 92 feet. This line would probably be very much cheaper as well as shorter and straighter than the present line; but if these advantages are all the other way, it would not much matter, for the saving in operating expenses would be an enormous percentage. With the same light engines and net loads which we have previously used for comparative purposes, the engine mileage per car round trip of 85 miles would be as 9.2 miles to 20.1 miles. Now it *may* be that this line would from wide and frequent gullies or other causes, encounter insuperable difficulties; but as it was not even examined, or at least not mentioned, it is altogether probable that the few miles required of grade over 60 feet per mile was the sole deterring influence. It was forgotten in searching for the costly chimera of a uniform gradient, which is a great deal worse than useless after it has been bought with a great price.

THE EFFECT OF A DIFFERENCE IN RULING GRADE ON THE COST OF DISTANCE, CURVATURE, AND RISE AND FALL.*

A difference in the rate of the ruling grades has a double effect upon the operative value of alternate alignments, of which we have heretofore considered only one. This separation was necessary in order not to confuse two entirely distinct questions, but we will now consider that part of the effect of high gradients which we have heretofore passed over. When the difference in ruling grade is marked, this question frequently becomes one of much importance.

The two distinct effects of high gradients referred to are as follows :

1st. *An increase in the* ENGINE TONNAGE REQUIRED *for a given business.*

This we have already considered and estimated for, in Tables D, E and F, pages 86, 92 and 94.

2d. *An increase in the* DIRECT COST *of every degree of curvature and every foot of distance and rise and fall,* DUE *to the greater engine tonnage.*

We may best show the importance of this latter item by an illustrative example. Let us suppose that we have two alternate lines, each 100 miles long and with precisely the same amount of curvature and rise and fall; but that the ruling gradients on one line are 40 feet per mile, and on the other line 80 feet per mile. Now the first impression of almost any one would be that, inasmuch as all the details of alignment except the ruling grade are the same on each line, they may be balanced against each other and neglected ; and that the sole difference in value between the two lines will be that resulting from the smaller *engine tonnage* required, the value of which may be determined from Tables E and F. But this view is erroneous, for it requires but little reflection to perceive that, inasmuch as more engines must be run over one line than the other, the line having the heavier gradients is more objectionable than the other *in proportion to the amount of curvature and rise and fall which there may be on both the lines alike*, and that hence it may make a very important difference in deciding on their relative values, whether they are lines of heavy curvature and much rise and fall or not.

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* This chapter and the following one on the "Relationship and Adjustment of the Minimum Radius of Curvature to the Maximum Grade" should properly have appeared in advance of the chapter on "Assistant Engines," but were unavoidably delayed in publication.

In order to estimate the importance of this difference, by referring to Table D, page 86, it will be seen that the number of trains required on the line having 80 feet grades will be 40×1.7=68 per cent. greater than on the other lines, and increasing this percentage by 8 per cent. on account of the great difference in grade, as set forth at the foot of Table D, we have 73½ per cent. The *exact* difference, as determined by comparing the relative net loads given in Table XVII., page 80, is 75 per cent., and we will, therefore, use that percentage. Now, it is evident that—to coin a somewhat odd phrase—the number of *train-degrees of curvature* will be 75 per cent. greater on the line having 80 feet grades; and hence that, before instituting a comparison between lines of different grades, the number of degrees of curvature and feet of rise and fall on the line having the higher grades should be *increased by the percentage which represents the excess in engine tonnage required on that line over that required on the given low grade line.* This constitutes the rule by which all such comparisons should be made.*

As respects the effect of *distance* on the comparative value of two identical lines, the correctness of this method is perfectly obvious; and the values of reducing grade given in Table E and F, pages 92 and 94, have been so given that they do, in fact, vary in proportion to the amount of distance which there may be in each line alike. Thus, if in our illustration above the two lines had been 120 miles long, the difference in operative value given by the table would have been 20 per cent greater; and that *this* should be so appears perfectly obvious to every one, because all are accustomed to consider the effect and cost of miles and train-miles. But exactly the same considerations which give a reduction of grade a certain value per *train-mile* of distance give it also a certain value per *train-degree* of curvature and per *train-foot* of rise and fall. For there is a certain cost to operate each degreee of curvative as well as to operate each mile of track, and this cost is, in each case alike, increased by an increase of grade. It follows that we might make out tables, similar to Tables E and F, giving the value of reducing grade per 1,000° of curvature, or per 100 feet of rise and fall, similar to those which we have already made out per 100 miles of distance, except that the method we have given above is simpler and better. In estimating for projected improvements on railways *already in operation*, the necessity of separately considering the effect of these various details of alignment on the value of reduccing grade disappears, for in that case, the curvature and rise and fall have *already* had their effect—much or little as may be, and just as much as the distance has—to increase those operating expenses by which (as set forth at the foot of Tables E and F) we gauge the value of reducing grade, and hence we are not obliged to consider separately either the one or the other. But in the case of a new road we have not this advantage, inasmuch as we cannot foresee the exact cost of each item of expense, and therefore we are obliged to consider separately the effect of each separate source of expense on the rude estimate of the cost of a train mile under the given special conditions, which we assume in the beginning.

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* There is a slight error in this rule, because the *additional* trains on the high-grade line cost much less than the average cost, but this difference is very small in the items *affected* by curvature and rise and fall, and such little error as there is very properly tends to favor he lower gradients.

Now we may proceed further. We have heretofore considered that the two lines were of equal length. But suppose, as would be nearly always the case, they differ in length as well as in ruling grades, as, for instance, instead of two lines each 100 miles long and having 40 and 80-feet grades, that one line is 100 miles long and has 40-feet grades, and the other line is 80 miles long and has 80-feet grades. The value of the difference in ruling grade is given in Tables E and F as so much *per* 100 *miles of line*, but shall we regard this value as applying to the length of the long line or the short one? The answer is, we may do either by using a little care, but preferably should proceed as follows: The original estimate of the probable number of daily trains will usually be made for the lower line, but for whichever line the *first* estimate be made, the engine tonnage on the high-grade line will be 75 per cent. greater than on the lower, as we have already seen. Then, the low-grade line has, for *eighty* miles of its length, an advantage over the other due to the difference in grade; but it then has the unbalanced disadvantage of having 20 miles further to haul. We may estimate the values of these differences from the tables we have given as follows:

In favor of line A, 40 feet reduction in ruling grade for 80 miles.		
Value (at 7 per ct.) by Table E (page 92) $7,577× 40 feet×80-100=	$242,464	
Increased by 8 per cent., for extent of reduction	19,397	
		$261,861
Against line A, 20 miles of distance.		
Value, by Table A (page 27), $3,900×20 miles=		$78,000
Net operating value of Line A over Line B, per daily train..		$183 861
Or, for an estimated business of 10 daily trains............		$1,838,610

This is the natural and preferable form of estimation, but we may also assume that the advantage of line A, due to its lower grade, extends over its entire length of 100 miles. But, *in that case*, we must deduct from the value obtained the value of 20 miles of distance, not on line A, but *on line B*, the high-grade line, which is greater than on line A in (very nearly) exact proportion to the greater number of trains required, or by about 75 per cent. We thus have:

In favor of line A, 40 feet lower ruling grades for 100 miles.		
Value, $7,577×40×100-100=	$303,080	
Increased by 8 per cent., as before..............	24,246	
		$327,326
In favor of line B, 20 miles of distance.		
Value, as before, $3,900×20×1.75 for increase in No. of trains..		$136,500
Net balance in favor of line A, per daily train...............		$190,800
Or, for a business of 10 trains daily............................		$1,908,000

The first estimate above is the more correct one. The difference of $69,390 (3½ per cent.) is due partly to neglect of decimals, but mainly to the error hinted at above, which is left for the careful reader to chase up for himself. We might easily do so, but fear to make too great drafts on his attention.

Now let us see how much this estimate might be modified by the amount of curvature and rise and fall. We will assume this to be precisely the same on each line, and as follows, viz., 10,000° of curvature (100° per mile on the longer line) and

1,800 feet of rise and fall (18 feet per mile). The Union Pacific Railroad in ascending to Aspen Summit has 84° per mile with very moderate difficulties. The Cincinnati Southern Railway on its heaviest operating division (from Somerset to Hunnicuts) has 22.5 feet of rise and fall and about 106° of curvature per mile, and this is on a very costly location, with maximums of 60 feet grades and 6° curves. Very many roads of the first class in various parts of the country have three and four times that amount of curvature per mile, and it will be admitted that our estimate is far from excessive.

These figures being assumed, we have already seen that the number of trains required on the high-grade line B is 75 per cent. greater than on line A, and consequently the number of *train-degrees of curvature* on line B will be 10,000° × 0.75 = 7,500° greater than on line A. Similarly the number of *train-feet of rise and fall* will be 1,800 × 0.75 = 1,350 feet greater than on line A. Then, from Tables B and C (pages 43 and 64), we have, in favor of line A:

7,500° of curvature × $3.48	$26,100
1,350 feet of rise and fall × $29.71	40,108
Total difference in operative value, due to the above items, per daily train	$66,208
Or, for a business of 10 daily trains	662,080
Total difference previously determined and caused by the difference in distance and train expenses, *independent* of the above items	$1,838,610
TRUE difference in operative value, *including* the effect of an identical amount of curvature on each line	$2,433,850

We will now assume that these two lines were so situated that the rise and fall and curvature were comparatively light, and yet that it still remains the same on each. As a standard we will take 22 miles of the Buffalo Division of the Erie Railway, between Portage Bridge and Burn's Station, which is perhaps a fair average of a line through moderately difficult farming country, and at points contains much curvature, with maximum grades of about 35 feet each way. The curvature for this distance averages 25° per mile, and the rise and fall 6.3 feet per mile. With these averages we should have on our assumed lines (taking the length of the longer one as before) 2,500° of curvature and 630 feet of rise and fall. The corresponding increase in the value of line A over line B, due to the effect of curvature and rise and fall, would be

2,500° of curvative × 0.75=1,875°, × $3.48=	$6.525
630 ft. of rise and fall × 0.75=472 feet × $29.71=	1,402
Total difference in operative value. due to above items, per daily train	$7,927
Or, for a business of 10 daily trains	79.927
Amount similarly determined above	662,080
Difference in the operative value of line A over line B, resulting from a varying amount of curvative and rise and fall, which still continues to be the same on each	$582,153

making a difference of about 33 per cent. in the original valuation, which neglected the varying disadvantage from the amount of curvature and rise and fall;—a sum not unworthy of attention. Yet the reader will admit that this sum was deduced by no strained or forced hypotheses, but by assuming variations which are exceedingly likely to occur in practice. This being so, it well illustrates the necessity of considering and *carefully estimating* every appreciable source of error in adjusting alignment, for every such error is multiplied, in the operation of railways, *by such enormous constants.* In no other branch of engineering is this true to anything like the same extent. Engineers might never have discovered that bridge chords need not be of equal section throughout, and the loss would not have been particularly serious to any one—because it is met and paid for once for all. But suppose that a single important railway has gradients reduced at great expense to an average between those best adapted for its unequal traffic, as *has* been done on many railways. It is hardly too much to say that the annual loss from *one* such blunder is enough to pay the interest on the cost of all the bridge chords of all the iron bridges in the United States. And yet the one art—although it is in great degree a matter of well understood routine for ordinary structures—has a voluminous and increasing literature; while the literature of the other is, so far as the writer's knowledge extends and with some inconsiderable exceptions, an utter blank. The consequence is what might be expected. There is no branch of engineering in which there are so many utterly incompetent men who fancy themselves, and are generally thought to be, very expert, as in railway location.

THE COMPARATIVE VALUE OF REDUCING THE LENGTH OF THE LINE AND THE RULING GRADES.

Although this question can be solved easily enough, in any given case, in the manner just shown above, there remains another mode which we may briefly consider, viz.: a process of "equating"—a vicious and unsatisfactory method as a rule, but of occasional convenience. For example, when, as is sometimes the case, we may adopt almost any grades at about the same aggregate cost by a proportional elongation of the line, what is the most economical gradient?

We have already seen, on page 24, that the cost of operating one additional mile is 42 cents per train, or $273 per year per daily train. For changes of several miles, however, such as we have now in view, this amount is too small, and should be increased by about one-third, for the reasons there set forth, giving us $364. Also, we have, by Table E, as the cost of increasing a level maximum grade by one foot per mile, $1,248 for a line 100 miles long, or $12.48 per mile of road. Hence, it is sufficiently obvious that to avoid an increase of one foot on a level grade we may lengthen the line by $\frac{\$1,248}{\$364} = 3.45$ miles. If the line were 200 miles long (and operated as a single division), we might lengthen it by twice that distance; and it is evident that we may say, *generally*, that we may lengthen *any* line having a level maximum grade by 3½ per cent. of its length to avoid an increase of one foot in grade; *i. e.*, a line 103.45 miles long with level grades will cost no more to operate than a line 100 miles long with grades of one foot per mile. But it does not follow from this that we can say that a level line 134.5 miles long will cost no more to operate than a line 100 miles long with grades of *ten* feet per mile, or a line 445 long with level grades than a line 100 miles long with grades of *one hundred* feet per mile. When we have to estimate for such considerable changes, the value of distance becomes much increased, and hence our percentage is correspondingly reduced. Therefore, the table which follows (Table J) and which was deduced in the manner outlined above, applies only to changes of about 20 per cent. or less in the length of the line. Moreover, the percentages given in the table are correct only when we may consider a reduction in grade as having a positive value for every train running over the line. For reasons which have already been set forth the writer regards this as a proper assumption in nearly all cases, but if it be not admitted, the percentages given should be decreased in proportion to the number of trains excluded. And in addition to this—and more important than all—the table given above must not be considered as applying to *single sharp inclines*, where the relative economy of using ASSISTANT ENGINES is an element of the problem. We shall consider that subject in our next paper, and therefore will now only add that the whole question of the adjustment of gradients is greatly modified when the conditions are such that assistant engines may be economically used.*

TABLE J.

SHOWING THE PERCENTAGE BY WHICH ANY LINE MAY BE LENGTHENED, IN ORDER TO REDUCE IT TO A GIVEN GRADE.

For minor changes only, not involving the use or disuse of assistant engines.

Grade after reduction.	Value per mile of avoiding addition to grade of 1 ft.	Value per mile of distance.	PERCENTAGE.
Level	$12.480	$364.00	.0345
10	9.672	"	.0267
20	7.488	"	.0206
30	6.240	"	.0172
40	5.304	"	.0146
50	4.680	"	.0130
60	4.368	"	.0120
80	3.744	"	.0103
100	3.432	"	.0095
150	2.808	"	.0077

RULE.—*Multiply the percentage opposite the grade to which the line is to be reduced by the number of feet of reduction involved.* Diminish percentage by 1-6, if over 20 per cent.

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* The writer perceives that these various distinctions which he feels compelled to draw are a tax on the attention of the reader; but he knows of no middle course between careful attention to all these details and blundering on by the rule of thumb. The latter is a very good rule in its place. and he sees no reason why—in minor matters, where there is no difficulty nor great expense in keeping on the safe side—it should not always continue to be the convenient friend of the puzzled engineer. But it is a terribly expensive rule for location.

From this table and the remarks preceding it, we may see that the distance by which we may lengthen a line, and consequently the grades to be adopted if they vary with that length, are strictly dependent upon the length of the operating division. For instance, if we have a line about 60 miles long and located under such topographical conditions that for 30 miles of that distance grades of 35 or 40 feet per mile are easily attained, but on the remainder the grades can only be reduced below 50 feet by elongating the line, we may lengthen the remaining 30 miles in order to reduce it to a 40 feet maximum by 60×.0146×10=8.76 miles, and if that grade could only be attained by lengthening the line ten miles, we could only afford to reduce the grade to about 43 feet per mile. But if the line had started from a point 40 miles further back in the low country, and hence been 100 miles long, we could have afforded to lengthen the same 30 miles by 100×0.0146×10=14.6 miles, *i. e.*. we could afford to reduce the grades to about 36 feet per mile. In this estimate we take no account of the possibility of using assistant engines nor of breaking up trains or divisions, which greatly modify the problem, as we shall see.

As practical examples of the comparative value of distance and low grades, we may instance, first, the following scrap, cut from the *Railroad Gazette* of Sept. 22, 1876:

> "*Cincinnati & Portsmouth.*—The contract for the construction of the entire line of this road from Cincinnati east by south to Portsmouth, O., has been let, and the road is to be finished ready for trains by May 1, 1877. The contract price is about $8,000 per mile. *The line is a pretty direct one, about* 100 *miles long, and has some heavy grades, one as high as* 142 *feet per mile.* The road is of 3 ft. gauge."

Now the writer feels a delicacy in commenting on the location of any narrow-gauge road, because he knows so little about them; and moreover, in the course of his present investigations, he has met with several well-authenticated reports of loads hauled on such roads which render it almost certain that the gauge has an effect on the laws of friction and gravitation which science has not yet determined. It is certainly possible, also, that the gradients of the above road could be kept lower and better adjusted on a direct line than by lengthening it. But as a general rule, and for old-fashioned railways, the words "direct line" and "heavy grades" have rarely any business to come into contiguity. If it had been a road of the ordinary kind, the engineer would have done well to go into a few of the calculations which we have been through at such length and discover that he might *well* afford to lengthen his line 5 or 6 miles for every 10 feet of reduction in grade.

As another illustration, we may analyze the justice of a heated controversy which arose in 1864 between the officers of the Union Pacific Railroad on one side and the Government and city of Omaha on the other, with reference to a purposed change of location which was subsequently adopted. The facts were as follows: The original location went almost directly west from Omaha, on a maximum grade of 66 feet per mile, to a point 22.7 miles distant therefrom in the valley of the Platte River. The new location made a detour from this line down the Missouri River for several miles, cutting out 9 miles of the old line and adding 17 miles to it, so that the total distance by the new line to the point in the Platte valley aforesaid was 30.7 miles. From that point westward the grades are 10 feet per mile going west and level coming east for several hundred miles. The maximum grade on the new line going west was 30 feet per mile.

With these premises, the very correct assumption was made that the distance from Omaha to the Platte valley would constitute in effect a separate division, whatever its length might be; and from our own tables, we have, as the comparative value of these two lines (allowing 7 per cent. for capital):

In favor of the new line, 36 feet reduction in grade, to 30 feet.

Value, by Table E, $\$8{,}914 \times 36 \times \frac{22.7}{100}$................=$72,846

Increased by 8 per cent on account of extent of change.. 5,828 ——— $78,674

In favor of the old line, 8 miles of distance:

Value by Table A, $3,900×8.......................=$31,200

Increased by 33 per cent. on account of extent of change.. 10,400 ——— 41,600

Net balance, showing the difference in operative value in favor of the longer and low-grade line, per daily train.........$37,074

The number of trains assumed by Colonel Seymour and by Colonel Simpson of the United States Engineers, in making their estimates of value, was 5 freight trains and 1.5 passenger trains daily over the lower line,* and multiplying the above sum by 6. 5 for the number of daily trains and by $1.86 for the estimated cost per train mile,

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* That is to say, the estimates were made in another form equivalent to this. The estimate of business has since proved to be excessive, as even at the present day the number of daily trains is only 1.6 passenger trains and 5.2 freight trains. But this was an error which the engineers in question shared with the whole country.

We have	$447,225
By Col. Simpson s and Col. Seymour's estimates, capitalizing the difference in the estimated yearly operating expenses (viz., $174,270 and $151,456) at 7 per cent., we have	$531,730
Deducting from this estimate 22 per cent., on account of 22 per cent. of general and station expenses, inaccurately assumed to vary with the alignment, we should have	$414,750

We see therefore that the adoption of the longer line was unquestionably justifiable, without considering the lower cost of construction or the government subsidy.

Now the rather remarkable identity between the above estimates—estimates made by as wholly dissimilar methods as can well be imagined—is, the writer begs to add, an entirely unforced coincidence, and was a wholly unexpected discovery after completing the above estimate. He takes this opportunity however, to point out and acknowledge an exceedingly plausible error into which he has fallen in a previous paper (page 73) viz., an assumption that the value of reducing grade is affected by a variation in the assumed rolling friction per ton.* Nothing seems plainer than that the rolling friction, which has such an important effect on the *actual* cost of operating a given grade, has an equal effect on the value of reducing it.

Yet this view is wholly erroneous. Whether the car friction assumed be 6 lbs. per ton or 60 lbs., the value of *reducing* grade is not affected a penny's worth, as, in fact, we have already pointed out at the foot of Table F, page 94. Therefore the writer's implied suggestion that Col. Seymour's estimate might have been affected by the subsidy question is not justified by the facts, and he regrets and recalls it. He must add, however, in justice to himself, that in the above error he has the company of Cols. Seymour and Simpson themselves, and, so far as he knows, of every engineer who has ever printed an estimate on the subject; and he may also add that the fact still remains that an erroneous premise was assumed with great care, although it fortunately had no vitiating effect on the *special* problem in view.

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* The precise language which the writer used was as follows: "It is plain that to unduly exaggerate the load which engines might haul *except* for gradients, is to unduly exaggerate the cost of the gradients themselves." This is true in the *letter*, but false in the spirit, and in the meaning which it was intended to convey. It *assumes* that the cost of increasing grade will follow the same law as the absolute cost of operating it, which is not the case.

THE RELATIONSHIP AND ADJUSTMENT OF THE MINIMUM RADIUS OF CURVATURE TO THE RATE OF THE MAXIMUM GRADIENTS.

If no other paper of this series has met the approval or commanded the attention of the reader, the writer hopes that in the discussion of the present subject he may receive the careful judgment of all those who have to do with the construction or improvement of railways. Although badly adjusted grades have a more calamitous effect on operating expenses, there is no problem connected with location which has such a grave effect on the COST OF CONSTRUCTION as the one we now propose to discuss, nor is there any in which such *discreditable* errors are committed by engineers at the present day from pure want of thought. It is indeed extraordinary that no one of the great number of expensive modern railways has seen fit to expend a few hundreds or thousands of dollars in exhaustive experiments and the collection of definite information as to this most important question which we propose now to consider, viz., the inter-relation of ruling gradients and curvature, and the maximum of each which may be used, separately or in combination with each other, without danger of injuriously affecting the capacity of the road. It is hoped to shed some needed light on this subject, or at least lay some foundation for an abler discussion.

It is the peculiarity of curvature that all its disadvantages lie upon the surface. A heavy grade is very unobtrusive: the most skillful and observant eye cannot detect differences of grade which decrease by a large percentage the operating value of the line. But curves attract instant attention, and their disadvantages appeal even more strongly to the imagination of the inexpert than to the enlightened judgment of the engineer. When we consider that it is both the duty and interest of locating engineers to please their unskillful employers, it is evident that this simple fact must always have a powerful if undetected influence, while human nature remains what it is, and if we further remember that, as a rule, the quickest path to reputation for a locating engineer is through rapidity of work in rushing through surveys, and that it is so much *easier* for him to locate a costly line made up of long straight grades and tangents than one skillfully adjusted at every point to topographical irregularities, in accordance with the exact conditions of operating economy, it will not be surprising if we find that these influences have tended to accumulate a mass of precedents which it requires some courage to defy. Fortunately, topographical and financial considerations have rendered it absolutely impossible in many cases to yield to such temptations, if any such exist, so that precedents are not wanting in either direction.

Passing from these considerations, however, and abandoning all prepossessions, we proceed to analyze, as nearly as may be, the causes which fix the advisable limit of maximum curvature and the cost of exceeding it. A moment's consideration will show that these may all be separated under the two following heads, sharply defined from each other:

1st. *The inherently greater costliness of sharp curvature*; that is to say, the greater wear and tear of road-bed and rolling stock and the greater consumption of fuel which results from 100 feet of 10° curvature rather than from 1,000 feet of 1° curvature.

2d. *The limiting effect of sharp curvature on the weight and length of trains.*

In other words, we are here met, on the threshold of the subject, with a distinction precisely analogous to that which exists in the case of gradients. *All* grades, without distinction and wherever situated, entail a certain additional expense per train passing over them; and, in addition to this, the *highest* rate of grade entails a certain and much greater expense which does not appear at all in the expenses per train mile, but solely in an increase in the number of trains. In like manner, *all* curves, without distinction, entail a certain additional cost per train mile for every degree of curve; and this cost, it may be or may not be—increases rapidly with the sharpness of the curve; but, in addition to this, the *sharpest* curves on the line *(if they be sharp enough)* will have the further effect of limiting the weight and length of trains.

At a certain definite radius, therefore, the expense arising from short radii takes a sudden jump. The inherent cost per train mile continues on as before, and, in addition thereto, there is a large additional expense on account of the limiting effect of any shorter radius upon the length of trains. A moment's consideration will show that this point is intimately connected with, and depends upon, the rate of the maximum grades, for the latter fixes the maximum length of trains, and the resistance of curves is itself a function of, or varies with, that length. Hence, the shorter the trains which can be hauled *independent* of the sharpest curve, the shorter the radius which may be freely used on levels or minor gradients without affecting the *number* of trains required for a given business.

Now, just as in the case of gradients, this distinction between these diverse sources of expense is one which must be carefully kept in mind if any correct and intelligent decision as to the limit of maximum curvature is to be reached. In the first place, it requires no great effort of mind to perceive that the *first* item mentioned above, viz., the INHERENT COSTLINESS of sharp curvature,—that portion which is visible in an increased cost per train mile for wear and tear and fuel,—affords no ground for the fixing of *any* arbitrary and inflexible limit of curvature, nor should it be considered or allowed to have *any weight whatever* in ascertaining at what radius to fix that limit. For, granting for a moment that the inherent cost of short radii per train mile increases as the square of the degree of curvature—an absurdly exaggerated estimate—it may easily be, and often is the case, that at certain points the cost of construction will vary as the cube of the degree of curvature; and hence a sudden sharp ravine might justify and require a 12° or 14° curve on this account alone, although 3° or 4° curves were the maximum on all the rest of the line. But what we *then* require to determine is, whether any such curve would have the further effect of limiting the weight of trains over the whole line, for in that case a large additional expenditure will be justifiable to increase its radius. This latter expenditure does not vary with the *number* of such curves, as in the former case, but is a certain fixed amount, and must be distributed among one curve or fifty according to their number. This fact alone is sufficient to show the essential dissimilarity between them. The inherent costliness of sharp curvature does certainly have its effect on the justifiable expense to increase the radius of *each particular curve*, for it is to be added in each case to the proportion for that curve of the estimated value of avoiding any limiting effect from its radius; but it does *not* form an element in fixing the point at which limiting effect begins, and hence should be allowed no weight whatever in ascertaining that limit.

All this seems clear enough when the attention is specially called to it, but—as with many other problems which advance from simple premises—it requires a constant effort of the mind to keep it always in view. Hence, although it has no real or necessary connection with our subject, we may first very briefly consider—

THE INHERENT COSTLINESS OF SHARP CURVATURE.

In the article on "Reduction of Curvature" already published, and especially in Table B (page 43), we have implied that the cost of curvature per degree slightly increases with the sharpness of the curve. Light is badly needed on this point, but the writer now regards this as an error, the result of an unconscious confusion on his own part of these wholly distinct questions which he is now endeavoring to separate. If the limiting effect of curvature be rigorously excluded from the mind, it does not seem probable that the *inherent* cost of curvature, per train mile per degree, is any greater on 10° curves than on 1° curves. The cost of fuel (6 cents*) is slightly increased per degree on sharp curves, as is also the cost of iron (7 cents), despite the great difference in the *length* of sharp and flat curves, as would more fully appear from an article on the "Wear of Rails from Grades and Curvature," which the writer hopes to prepare, from data in his possession, at some future time; but, on the other hand, the cost of maintaining road bed and track (6.5 cents) is very greatly decreased; for it is nearly constant per 100 feet of curve, and sharp curves are very much shorter. Moreover, sharp curves *lengthen short tangents*, a consideration of the highest importance which engineers too frequently overlook; and hence a sharper curve doubtless often results in less resistance and wear and tear. The greatest element of the inherent cost of sharp curvature is that the length of the line is always greater between the same tangents, but this is an element given by the comparative surveys (although it may be determined by the table given in the "Note on Reduction of Radius of Curvature" on page 48, and hence does not *apparently*, although it does *really*, enter into the question.

We may, therefore, perhaps assume that the inherent cost of curvature per train mile is independent of the radius, and this simplifies some questions connected with curvature. But whether the reader be prepared to admit this conclusion or not is a matter of perfect indifference for deciding upon the question in hand, as, it is hoped, has been made perfectly clear.

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* These sums refer to the estimated cost per train mile of each item for an amount of curvature equal in resistance to one mile of straight and level track, given on page 44.

Dismissing therefore from our minds this confusing and irrelevant question, we will now submit our SECOND question above, the limiting effect of curvature, to the arbitrament of fact.

THE LIMITING EFFECT OF CURVATURE UPON THE WEIGHT AND LENGTH OF TRAINS.

If we know the greatest length and weight of train which can be hauled up the maximum grade of any given road by the most powerful engines which will probably be used; the curve around which the same engine can haul the same train *on a level*, without greater resistance, is evidently the proper limit—*and the only proper limit*—of maximum curvature. This curve may also be freely used on the maximum or any other grade, by reducing the grade to a level for the length of the curve, and an adequate distance beyond it, without danger of limiting the weight of trains. We assume that the maximum grade occurs only on tangents, but, if curves are introduced upon it without ample compensating reduction, it in effect increases the maximum grade; hence shortens the possible length of train; and hence shortens the minimum radius which may be used on a level without limiting effect. We shall have occasion hereafter to consider the propriety of such practice.

The reader is requested to admit the above premises before reading further.

We have on the maximum grade two resistances to overcome:

1st. The ordinary rolling friction.

2d. The resistance of gravity;—a known and constant quantity given in Table XVII., page 80.

In the case of curvature on a level we have also two resistances:

1st. The ordinary rolling friction, as before.

2d. All additional resistance which may or can arise from the curve.

What we require is, that the sum of the two latter resistances shall be less than (or no greater than) the sum of the two former; and it is evident that the resistance from the rolling friction proper, being the same in each case, whatever its amount may be, may be entirely neglected. We have left only to determine what is the degree of the curve which, *in all cases and under the most unfavorable circumstances*, will oppose no greater additional resistance to the longest and heaviest trains than the resistance from gravity only on the maximum grade.

We may express the problem to be solved most concisely and clearly by the aid of a little algebra, of the mildest description.

If we let x = the required degree of maximum curvature;
c = the resistance in lbs. per ton per degree of curvature, on an x degree curve, *per* 100 *feet occupied by the train;*
l = the longest train which can be hauled up the maximum grade by the heaviest engine in use;
g = the resistance in lbs. per ton due to gravity only on the given maximum grade:

then what we require in order to fix a maximum degree of curvature, x, is that, in all cases,

$$x\,c\,l < g. \quad (1)$$

If, however, we are careful to assign the *largest possible values* (within reason) to c and l, we may determine x by giving this inequality the form of an equation, viz.:

$$x\,c\,l = g, \quad (2)$$

whence we have,

$$x = \frac{g}{c\,l}, \quad (3)$$

or,

$$x\,c = \frac{g}{l}. \quad (4)$$

To solve this equation, we require to determine maximum values for c and l.

The longest trains which may be hauled up grades (value of l). This is a simple question of fact. The longest possible train is one of empty cars. Its absolute length is directly as the weight on drivers, and inversely as the rolling friction and adhesion assumed. We may assume the heaviest engines in common use (see Tables XV. and XVI. pages 74 and 75) as 35 tons on drivers, 60 tons gross, including half-loaded tender. As for the rolling friction, very extended experience in this country and Europe shows that 7 lbs. per ton is about the lowest which can be realized in daily practice on straight grades at moderate speeds. We might substantiate this by numberless authorities, among others by some recent and valuable experiments with heavy trains on the Lake Shore & Michigan Southern Railway by Mr. P. H. Dudley with his dynograph. (See Trans. Am. Soc. Civ. Engrs., October, 1876). The lowest rolling friction there realized was 6.88 lbs. In respect to the ratio of adhesion, there is no variable element in the management of railways more nearly invariable than that, in the daily routine of business, trains are unconsciously adjusted to an adhesion of about $\frac{1}{5}$ at the points of maximum resistance. The trains above referred to, which we may assume to have been as heavy as was prudent (although at the same time they

TABLE XXV.

Showing the Maximum Trains of loaded and empty cars which can be hauled up various straight grades (uncomplicated by curvature) in the daily routine of business by the heaviest engines in common use on American Railways (35 tons on drivers, 60 tons gross including tender).

Rolling friction assumed at 7 lbs. per ton.

Grade in feet per mile...	Resist. grav. + 7 lbs. roll. fric. (lbs. per ton.)	Tons wt. of train.		No. of cars in train.		Tot. length of trains (in 100 ft. stations).		Values of $\frac{g}{l} = \frac{\text{resist. grav.}}{\text{length train}}$	
		Gross........	Net..........	Empty (9 tons)	Loaded (18 tons.......	Empty cars..	Loaded cars...	For empty cars........	For loaded cars........
Lev	7.0	2,000	1,940	215	108	72.20	36.50	0.000	0.000
10	10.8	1,296	1,236	137	69	46.20	23.50	0.081	0.160
20	14.6	959	899	100	50	33.80	17.80	0.225	0.427
30	18.4	749	689	76	38	25.80	13.20	0.440	0.860
40	22.2	631	571	63	32	21.50	11.20	0.705	1.35
50	25.9	541	481	53	27	18.20	9.50	1.04	2.00
60	29.7	471	411	46	23	15.80	8.20	1.44	2.77
70	33.5	418	358	40	20	13.80	7.20	1.92	3.69
80	37.3	375	315	35	17	12.20	6.20	2.48	4.89
90	41.1	341	281	31	15	10.80	5.50	3.15	6.20
100	44.9	312	252	28	14	9.80	5.20	3.87	7.28
120	52.5	267	207	23	11	8.20	4.20	5.54	10.04
150	63.8	220	160	18	9	6.50	3.50	8.75	16.25
200	82.8	169	109	12	6	4.50	2.50	16.90	30.30

Remark.—This table differs from Table XVII., page 80, in that it is made up for a minimum rolling friction of 7 lbs. per ton instead of 10 lbs. per ton; the latter being the rolling friction which is indicated by the loads hauled on various grades which are complicated by curvature. The difference, however, is not due to the *direct resistance* caused by the curves, for that is the same on each grade, like the rolling friction proper; but is probably owing to the limiting effect of such curves on trains in excess of the apparent resistance. The above loads are hauled *in daily practice* on roads of light curvature and grades.

The last two columns above give values of the function $\frac{g}{l}$ which is required in solving eq. (4) p. 172.

would appear to be in approximate accordance with the daily practice of the line) were adjusted to an adhesion of 1-4.88. These data given, we may construct the preceding table (Table XXV.) of maximum trains.

In the last two columns of this table are given values of

$$\frac{g}{l}\left\{\frac{\textit{i. e.}\text{, resist. grav. per ton}}{\text{length train in 100 ft. stat'ns}}\right\}$$

which we require in solving the formula above (Eq. 4).

Maximum Resistance in lbs. per ton per degree of curvature per 100 feet of train (value of c). On no scientific question of financial importance is there such a dearth of definite knowledge as on this. The writer has been obliged to evolve an approximation out of his inner consciousness and finally test it by known facts ; of which, fortunately, he was able by diligent effort to collect a considerable mass, which may be found embodied in Tables XXVII.—A and XXVII.—B.

Molesworth guesses in his Pocket Book (old edition p. 40) that the *average* value of c "may be taken as" 1 per cent. of the rolling friction per degree of curvature. This was for curvature of average sharpness with inflexible wheel bases, and we may assume it as measuring the *maximum* resistance with a flexible wheel base for very flat curves of 1° and 2°. This percentage, however, undoubtedly increases somewhat faster than the degree of curvature, and on a 10° curve we will assume that it is as much as *double*, or 2 per cent. This assumption we shall finally see to be beyond the indications of experience, as indeed it should be. For curves of more than 10° or 12°, the percentage undoubtedly increases much more rapidly until we reach a superior limit fixed by the experience of Mr. Charles Ellet on the Virginia Central Railroad. Mr. Ellet found on the "Mountain Top track" that a reduction of 58.4 feet per mile was not quite sufficient to compensate for the effect of a 19° curve (300 ft. radius) with trains 120 to 150 feet long. The resistance of gravity on a grade of 58.4 feet = 22 lbs.; 22 lbs. ÷ 19° = 1.15 lbs. per degree of curvature, and 1.15 lbs. ÷ 1.20 = 0.925 lbs. per ton per degree of curvature per 100 feet occupied by the train = 9¼ per cent. of the rolling friction (10 lbs. in this case). Assuming 10 per cent. and 18° curves as the superior limit, we may construct Table XXVI., the manner of doing which will be sufficiently evident on examination.

TABLE XXVI.

Showing the maximum percentage which the resistance arising from curvature per 100 feet of train bears to the rolling friction proper.

As substantiated by the experience with limiting curvature of all American railways, as shown in Tables XXVII.—A and XXVII.—B.

Degree of Curvature.	Percentage of curve resistance per 100 feet of train to the rolling friction proper.		Total resistance of curve in lbs. per ton per 100 ft. of train = per cent. in previous column × 7 lbs. per ton.
	Per degree of curve.	Total.	
1°	1 p. c. × 1 =	1. p c.	0.07 lbs. per 100 ft. of tr'n.
2°	1 " × 2 =	2. "	0.14 " " "
3°	1.1 " × 3 =	3.3 "	0.23 " " "
4°	1.2 " × 4 =	4.8 "	0.336 " " "
5°	1.3 " × 5 =	6.5 "	0.450 " " "
6°	1.4 " × 6 =	8.4 "	0.588 " " "
7°	1.5 " × 7 =	10.5 "	0.735 " " "
8°	1.6 " × 8 =	12.8 "	0.896 " " "
9°	1.8 " × 9 =	16.2 "	1.134 " " "
10°	2. " × 10 =	20.0 "	1.4 " " "
11°	2.4 " × 11 =	26.4 "	1.848 " " "
12°	2.8 " × 12 =	33.6 "	2.352 " " "
13°	3.2 " × 13 =	41.6 "	2.912 " " "
14°	4.0 " × 14 =	56 0 "	3.92 " " "
15°	5.0 " × 15 =	75.0 "	5.25 " " "
16°	6.0 " × 16 =	96.0 "	6.72 " " "
17°	8.0 " × 17 =	136.0 "	9.52 " " "
18°	10.0 " × 18 =	180.0 "	12.6 " " "

Remarks.—The rolling friction is assumed at 7 lbs. per ton, the same as in Table XXV. If it were assumed higher, the aggregate curve resistance would be higher. but the length of train proportionately shortened so that the result would be the same.

The preceding table gives a very large aggregate curve resistance. Thus, for a train 1,600 ft. long (about 46 cars) on a 10° curve we have 1.4 lbs. × 16=22.4 lbs. per ton, this being equivalent to the resistance from gravity only on a 60 ft. grade. This excess over the actual resistance, however, is essential in order to include the full *limiting effect* which curves have in excess of their nominal resistance as pointed out below.

The latter column of Table XXVI. gives the values of $x\,c$ which we require in order to solve equation (4) above. We have already determined maximum values of $\frac{g}{l}$ (see Table XXV.); and, by interpolating those values in the last column of Table XXVI. above, we shall have opposite to it the corresponding value of x required. For example: the value of $\frac{g}{l}$ for a 60-feet grade is, for empty cars, 1.44 lbs. per ton. Interpolating this value in Table XXVI., we find the corresponding value of $x\,c$ to be opposite a 10° + curve, the latter being, consequently, the degree of the curve which, under no circumstances which can properly be provided for, will oppose as great a resistance to the longest and heaviest trains as will be encountered from gravity only on the maximum grade.

Table M. gives the degrees of curvature thus deduced, and its construction and manner of application will now be sufficiently evident by an examination of the table itself with its accompanying notes.

TABLE M.

SHOWING THE CURVE ON A LEVEL WHICH WILL HAVE LESS LIMITING EFFECT THAN ANY GIVEN STRAIGHT GRADE ON A TANGENT, ON THE LONGEST TRAINS OF LOADED OR EMPTY CARS WHICH CAN BE HAULED UP THAT GRADE BY THE HEAVIEST ENGINES IN COMMON USE (35 tons on drivers, 60 tons gross).

As substantiated by the average daily experience of all American railways as set forth in Tables XXVII.—A and XXVII.—B.

Rate of Maximum Grade on Tangents.	Curve of equal resistance on a level.	
	Trains of Empty Cars.	Trains of Loaded Cars.
Level.	Tangent.	Tangent.
10	1° 10′	2° 10′
20	3°	4° 50′
30	5°	7° 50′
40	6° 50′	9° 50′
50	8° 30′	11° 20′
60	10°	12° 40′
70	11°	13° 40′
80	12°	14° 40′
90	13°	15° 30′
100	14°	16° 10′
120	15°	17° 10′
150	16° 40′	18° +
	18° +	18° +

REMARKS.—This table is deduced by comparison between Tables XXV. and XXVI., as set forth in the text, and is believed to err on the safe side. As it rests solely on rudely-observed facts, however, and not on experimental data, it is liable to err slightly in either direction on the higher curves.

Reversed curves cause a greater inherent expense for wear and tear, than simple curves, but—if they be connected by tangents not less than 50 feet long per degree of curve—they cause no appreciable loss of power over a continuous curve.

Curves shorter than the average train length may properly be made somewhat sharper than the above table indicates in proportion to their shortness, when occasion arises. This difference, however, should hardly be more than 1° for a curve half a train-length long.

The reduction in grade for curves should never be less than 0.1 per station to eliminate their limiting effect, as set forth in the text. This reduction, moreover, should *in all cases* extend half a train-length above the curve at the upper end. On the other hand, it may begin about ¼ of a train-length on the curve at the lower end. These (and all) changes of grade should be connected by long and easy vertical curves.

Trains are never fully loaded even with an evenly balanced traffic. The best average practically possible in the latter case is about ⅔ of a load. See remarks below, on page 183.

us limiting curves on various Railways,

en.)

ND CURVATURE.		DEDUCTIONS FROM STATISTICS.					
urvature.							
Max. length of max. curve.		Assumed Rate of Adhesion.	Total power of Engine.	Minimum train resistn'c on tangents.	Remainder, showing max. resist. of curve		Do. by Tab. XXVI ×length of train.
In deg's	In ft.				Total.	Lbs. per ton.	
......	....	.....	....	....	....	9.0 lbs	3.42 lbs
30°	500	1-5	15,000 lb	6,797 lbs	8,203 lbs	8.45	9.14
54°52′	878	"	15,000	12,800	2,200	5.1	3.90
112°	1,562	"	15,000	8.014	6,986	11.1	7.35
160° ±	2,000 ±	"	13.000	11,878	1,122	4.0	4.05
95° ±	1,000 ±	"	16.000	9,783	6,217	7.1	13.0
95° ±	1,000 ±	"	16,000	9,560	6,440	7.5	17.25
95°	1,000 ±	"	12,200	10,462	1,738	8.1	4.0
95°	1,000 ±	"	16,000	12,945	3,055	11.5	4.75
40°30′	405	"	15,000	7,111	7,889	18.3	9.1
180°	>1,250	"	12,000	10,690	1,310	8.2	8.28
180° ±	950 ±	"	11.000	7.060	3.940	55.9	22.1
180° ±	950 ±	"	11,000	7,260	3.740	51.6	28.0
180° ±	950 ±	¼	18,667	12,420	6,247	104.1	11.2
180° ±	950 ±	¼	18,667	15.525	3,142	41.9	15.3
revers.	.....	⅓	14.933	13,100	1,833	4.5	163.2

possibly be considered as arising from the curve, as deduced by
tio of adhesion was taken at 1-5, except in a few cases, as noted,
ch as *tax* the engine, but simply those which are regularly hauled
um for daily practice. In nearly all cases above from one to three
able were obtained by personal application to the officials of the
ce.

ain as deduced by multiplying its actual length in stations by the
e remembered that these train lengths are in all cases very much
in preparing Table M. is by so much diminished. Thus, in the
me engine would handle 473 tons (including its own weight) on a
ereas multiplying the actual length of the train (5.8 stations) by
ng Table M. we assumed that trains on such a grade would be
ily close correspondence, considering that this was for a curve
er by Mr. Fink), according to some undetermined law. A similar
s of that which experience indicates.

hout the table for the actual resistance arising from the curve. It
per ton, yet it is conclusively shown by the effect of the grade

r from time to time and which in this case was vouched for by no
ly) by Robert Fairlie himself, Chief Engineer Russian Department
han 0.3 the engine could not move the train at all on the given
e was only 4½ lbs., or about ¼ lbs. per degree! Our rule would

ces on *various Railways,*

TURE.	DEDUCTIONS FROM STATISTICS.				
th of rve. n ft.	Total power of Engine.	Minimum train resistn'e on tangents.	Remainder, showing max. resist. of curve.		Do. by Tab. XXVI ×length of train.
			Total.	Lbs. per ton.	
,200	9,600	5,990	3,610	7.4	9.44
500	15,000	4.697	10,303	15.35	12 1
405	15,000	12,504	2,496	5.9	7.6
.562	15,000	6.617	8,383	16.0	11.6
060±	19.200	16.440	2,760	6.9	9.9
,000±	16,000	7.327	8.673	13.2	25.6
.000±	16,000	6,433	9.567	16 6	22.6
,000±	16.000	13.905	2,095	7 0	10.6
405	15,000	6,947	8,053	19 1	17.1
ed.	15,600	12,600	3,000	17.4	16.2
700	12,000	11,080	920	4.0	53.93
950±	11.000	5,577	5,423	94.3	28.2
ever.	8,760	5,177	3,583	25.1	204.0
"	8.760	5.177	3,583	25 1	408.0

reported to the writer as loads hauled in the
e most important branches into the coal regions,

The answer can only be one of three reasons:

1st. A 7° or 8° or 10° curve of the same angular length is so enormously more costly in wear and tear that *in no single case* on this costly line would the saving in cost of construction have paid for the loss therefrom; or—

2d. A 7° curve on a 45-feet grade, or an 8° curve on a 30-feet grade, on a 10° curve on a level has such a *powerful limiting effect upon trains* that the same engine would not haul the same train around them as around a 6° curve on a 60-feet grade; or—

3d. A 7° or 8° or 10° curve is so *exceedingly unsafe* that the additional danger therefrom would in no case have been repaid by an adequate economy in construction.

There is no escape from accepting some horn of this trilemma, if the standard adopted is to be justified at all;—and any man who could maintain any one of them must be wandering in mind. In commenting upon such an utter and evident blunder as this, it is difficult to maintain that tone of moderation and courtesy which should characterize a scientific discussion. When we consider that every one of the great trunk lines has 8° or 9° or 10° curves and moves more cars over them in a month with unsurpassed efficiency and economy than the Cincinnati Southern Railway will ever move in a year; when we consider that many railways of large traffic have 10° and 12° curves which result in no serious danger or expense per train mile; what is the Cincinnati Southern Railway that it should set up an inflexible standard of this kind and stick to it regardless of cost; even if it had saved a trifle in expenses or danger, which is very doubtful? We pass to the second branch of our subject, viz., the propriety of allowing no grades higher than 60 feet per mile, and yet having 6° curves on that grade.

This standard we may regard with more patience, for it may be plausibly justified by such reasoning as this: That on the whole the *average* is about the same; that if grades are lower on curves they must be higher on tangents; and that engines would lose on the tangents all that they gained on the curves. In other words, this position assumes that in the daily routine of business engines may be relied on to do a little more work on curves than they could continuously; because on the intervening tangents they will have a little *less* work to do, and will thus accumulate steam and get up headway to carry them through the next curve. It follows that if higher grades were used on tangents than on curves, the engine could not do this, and hence the higher grades would have a limiting effect on trains, and injuriously affect the value of the line. The writer hopes he has stated this position fairly and forcibly.

The first fallacy in this reasoning is a neglect of the elementary principles of the steam-engine. We can overcome momentarily excessive resistances in only two ways. The first of these is by varying the point of cut-off and using more steam for the moment than we can produce continuously. The wasteful effect of this practice, when the engine is already working close to its full power, is shown without further demonstration in Table XXVIII. It is sufficiently evident that if we were to *spurt* around occasional curves in this manner the engine would need to be relieved of 3 to 4 foot-pounds of work elsewhere for every foot-pound thus performed.

TABLE XXVIII.

Showing the cost in steam of any additional power gained by varying the point of cut off.

Point of Cut off.	Increase p. c. in steam used.	Average pressure (initial pressure 100 lbs.)	Increase p. c. in power.	Increase p. c. in power per 100 p. c. increase in steam used
⅛........	....	38.5 lbs.	....	....
¼........	100 p. c.	59.6 “	54.8 p. c.	54.8 p. c.
⅜........	50 “	74.2 “	24.5 “	49. “
½........	33⅓ “	84.6 “	14.4 “	43.2 “
⅝........	25 “	91.9 “	8.6 “	34.4 “
¾........	20 “	96.4 “	4.9 “	24.5 “
⅞........	16⅔ “	99.2 “	2.8 “	16.8 “

REMARKS.—The average pressure is computed by the ordinary formula for steam used expansively, to be found in any of the pocket-books (except Trautwine). The above table represents about the extreme variations as to cut-off for the locomotive engine.

As a matter-of-fact, no runner ever resorts to this practice as an habitual reliance and the only other method of equalizing an unequal resistance is by *acquiring momentum*, or, in other words, by a constant alternation of high and low speeds. This butting process is excessively expensive at best, for the speed must be considerable if the accumulated momentum is to be of much service. Every time the locomotive enters or leaves a curve, a shock more or less severe runs through the train, and this kind of action is one great cause of locomotives wearing out so much more rapidly than stationary engines; as any one will perceive who will consider the effect on a stationary engine, *running without a governor*, of rapid changes of load or speed. In order to *economize* in construction we must often put up with this disadvantage and introduce varying resistances, but to *expend money* to do so by keeping down tangent grades to the curve maximum is the worst of bad practice.§ But, even if the process were inexpensive.

2*d*. As soon as the adhesion is lessened for any reason the *possibility* of this course is destroyed; for a low speed is then unavoidable and there is no available momentum. The same is true if trains are stopped or steam production checked for any cause on ruling grades. Now all trains are at all times exposed to such contingencies, and no railway can afford to, or does, *take chances* in such matters or vary its practice according to the daily "probabilities." It will, and should, adopt such habitual loads as are *sure* of going through without stalling; and the inevitable effect is that trains are adjusted, not to an average between the tangent and curve resistance, but to the *maximum* resistance in the strict sense of the word. But, granting that this averaging or butting process is both inexpensive and possible, on curves of moderate length.

3*d*. The Cincinnati Southern (and most other such railways) is estopped from pleading either of the above arguments, because the curves on the maximum grades are so frequent and long that the butting process is *under any circumstances* an impossibility. The writer heard of one curve over 2,000 feet long (120°) on the maximum grade, with others approaching that limit in close proximity. On many railways even longer curves are introduced. No momentum can be relied on to carry trains around such curves, even if there were opportunity to accumulate it, which can never be relied on. But (here we enter on an argument of still greater force), even if such curves be all short and our previous reasoning has no force whatever.

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§ It is not uncommon to hear engineers reason by analogy from the horse. and actually *advocate* this process, recommending that short stretches of level be introduced in maximum grades to enable the engine to get up headway. No error could be more gross or ruinous. The economy of this practice in the case of the horse rests on physiological reasons, but the locomotive has no muscles to be relieved. It is a simple problem of so much steam, so much work in such and such a time. The necessary foot-pounds of work for a given distance are increased instead of diminished by the levels, and steam is used far less economically than if the *whole* grade were uniformly reduced by a corresponding amount. It is doubtless true that if we could cut up all our maximum grades into short sections of one to three miles we should appreciably benefit the line; but *short* breaks of grade (between stations) for other than topographical reasons are always disadvantageous.

4th. The arguments by which the averaging theory is justified neglect some important facts as to the nature of curve resistance. The writer had hoped to base this paper upon a scientific demonstration of the exact nature and extent of these forces by an engineer whose well-earned fame would carry an authority which his own words cannot; but the requisite experimental data were not available, and as they would involve the expenditure of a few hundred dollars by some railway, they probably never will be available. Fortunately, however, the statements we shall make are of such a character that every practical reader will recognize that such facts exist and are operative to some unknown extent, notwithstanding the fact that the statements made are of necessity based solely on the writer's rude deductions from observed facts.

The law of curve resistance is such that the *average resistance per ton*, and the *limiting effect* of curvature, have very little connection. When a train is bowling along at a fair rate of speed under full control, the curve resistance is comparatively a minor matter; but as soon as, for any reason, the train begins to *labor* on the curve, and speed is checked, the resistance, even in pounds per ton, is increased to a greater or less extent, on account of the fact that the lateral resistance caused by the super-elevation and obliquity of draft, is no longer balanced in any degree by centrifugal force. How much or little effect this cause may have cannot at present be determined, on account of the profundity of professional ignorance on this subject; but it is a matter of general notoriety that it has *some* effect, and there is another fact to be considered of far greater importance. The resistance caused by each car is not uniform, as on a grade. Of the various lateral forces which in the aggregate cause the greater portion of curve resistance (for the slipping of wheels resolves itself into a lateral force), an important element is that caused by the obliquity of draft, and this increases in a geometrical ratio (more or less rapid according to undetermined laws) with the length of the train, *and with the grade on the curve.*[‖] The last cars undoubtedly

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[‖] For an appreciation of this latter (and generally unrecognized) fact, the writer is indebted to Mr. Albert Fink, and if we might hope that any one would ever *thoroughly* investigate the action of all these forces, it might possibly prove an element of much importance in the economy of curvature. How far and to what extent the *tractive* resistance varies with the action of the lateral forces is wholly a matter of conjecture; but the lateral resultant from obliquity of draft on a 6° curve is more than three times as great on a 60-feet grade as on a level. It is not probable that the *longitudinal* resistance varies in *anything like* this proportion, but it must at least have an effect of appreciable importance.

cause a considerably greater resistance than the average of the whole train.

Now, however difficult it may be to determine the effect of all these forces theoretically, the locomotive runner is not long in finding it out practically. He is loaded, perhaps, with trains of 30 cars, and finds he is sometimes stalled. His train is then cut down to 27 or 28 cars. *Now* the conditions are entirely different. He has ample power, and hence no need of it; and if the resistance of such a train were measured on 60-feet grades + 6° curves, it would probably be found that it was only equivalent to about 68 or 70 feet per mile. *But if it should be attempted to reload his engine to anything like its full capacity as thus indicated*, it would at once be found that the resistance would mount up, under *unfavorable* conditions, to that arising from a grade of 80 or 84 feet per mile, and his train would be stalled. Now, it is self-evident that we may (and should) so design our alignment that engines may always *be* loaded to their full working capacity at any or all points, and hence 80 or 84 feet per mile is the equivalent straight grade which we may freely use; and yet it is very true that, if we do so, the resistance in the daily routine of business, would undoubtedly be higher on the 84-feet grades than on 60-feet grades + 6° curves; *but this over-plus of power on the latter is absolutely essential*, in order that the curve resistance, largely caused by the *last cars* of a train, may be in no danger of so mounting up on us that we cannot handle our train at all. By using a *little* lower grades on tangents—say 70 or 75 feet per mile—we might then trust *a little* to the butting process, and possibly squeeze through a car or two more than if we used 84-feet grades, at a cost about twice as great as if hauled in a separate train. It does not require demonstration that no engineer is justified in reducing grades for such a purpose if it adds anything whatever to the length and cost of his line.

We have tried to make this argument as clear and plain as its importance demands; but, for any one who cannot or will not admit it, we add unimpeachable facts. We have claimed that the Cincinnati Southern alignment is equivalent in limiting effect to a straight grade of 80 or 84 feet. Referring to Table XXV., p. 173, the corresponding net load of empty cars for a 35-ton engine (on drivers) is 33 to 35 cars. Long experience on the Eastern Division of the Erie Railway has shown that the maximum load of empty cars hauled in daily practice over 60-

feet grades+5° curves is 35 to 40 cars by a 37½ ton engine. This proves the fact Q. E. D., for nothing is more fully established by experience than that a 35-ton engine might be relied on to haul nearly or quite 46 empty cars on a *straight* 60-feet grade, as indicated in Table XXV. (this corresponding to a rolling friction of 7 lbs. per ton), if all curves were *heavily* and *amply* reduced. The latter is the vital point. All or nearly all high-grade railways are needlessly suffering from the effect of limiting curvature, because, if a reduction of grade has been attempted at all, it is too little to be of real service; and consequently very few railroad men appreciate what heavy loads might be hauled on straight maximum grades. For example: the Central Pacific and many others reduced 0.05 per station per degree; and the Pennsylvania, the Baltimore & Ohio and others, only 0.02 per station. This is little better than nothing. It may equalize the *average resistance*, but to equalize the *limiting effect* the reduction should be about 0.1 per 100 feet, or 5 feet per mile. The effect of this error is visible in the fact that the trains hauled on these and many other railways are *apparently* adjusted to a rolling friction of 10 lbs. per ton instead of 7 lbs., as we have already pointed out; and yet these same trains will in no case give evidence through a dynamometer of a higher rolling friction than about 7 or 8 lbs. per ton; and the latter is actually realized *in daily practice* on the Lake Shore** and many other railways of easy curvature and grades. The writer has once explained this curious fact as probably due to the allowance for emergencies which experience has shown to be advisable; but further investigation leads him to believe that this explanation is true only when taken in connection with the considerations above advanced. *Some* railways, favored by nature, do not find it necessary to provide for such emergencies. Moreover, all grade reduction for curvature should begin a short distance *on* the curve at its lower end and end half a train-length *beyond* the curve at the upper end, for evident reasons which we cannot enter into. These grades should also be connected by LONG AND EASY vertical curves. If all these minutiæ be not attended to, we shall still have limiting effect from curvature; but, if we do so, we may use very sharp curves when necessary to economize in construction. For example, in the case of the Erie Railway above, the same

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** See Journal Am. Soc. Civ. Engrs., October, 1876, p. 341.

trains are hauled with less difficulty around a 10° curve on a 25-feet grade than up the maximum grade, as will be seen by referring to Table XXVII.—A and B.†† A lesson of great value to the Cincinnati Southern Railway might have been learned from that curve, at no greater cost than about $12.50 out of $12,500,000 for a ticket to New York.

Now what the railway in question (as well as many others) *should* have done, was to adopt no inflexible standard of either grades or curvature. A little of that admirable care which has given it such excellent eye-bars should have been diverted to the construction of a well-devised *sliding scale of adjustment* between grades and curvature. Information should have been

TABLE N.

SHOWING A GRADUATED SCALE OF ADJUSTMENT BETWEEN GRADES AND CURVATURE; BEING VARIOUS COMBINATIONS OF EACH WHICH HAVE AN EQUAL LIMITING EFFECT ON THE LONGEST AND HEAVIEST TRAINS.

Adapted for a road having maxima of 60-feet grades + 6° *curves.*

In combination with a grade of		The maximum curvature permissible is	Possible modification of table for more perfect safety.		
feet per station.	ft. per mile.		feet per station.	feet per mile.	Curve.
1.6	**84 ft.**	**Tangent**	1.5	79	tang.
1.5	79 “	1° 30′	1.4	74	2°
1.4	74 “	3°	1.3	69	3° 30′
1.3	69 “	4°	1.2	63	5°
1.2	63 “	5°	1.1	58	6°
1.1	**58** “	**6°**	1 0	53	7°
1.0	53 “	7°	0.9	48	8°
0.9	48 “	8°	0.8	42	8° 30′
0.8	42 “	9°	0.7	37	9°
0.7	37 “	9° 30′	0.6	32	9° 20′
0.6	32 “	10°	0.5	26	9° 40′
0.5	26 “	10° 30	0.4	21	10°
0.4	21 “	11°	0.3	16	10° 15′
0.3	16 “	11° 30	0.2	11	10° 30′
0.2	11 “	12°	0.1	5	10° 45′
0.1	5 “	12° 30′	0.0	Level	11°
0 **0**	**Level.**	**13°**			

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†† Special inquiries made, at the writer's request, by Mr. Jacob Keene, Roadmaster of the Eastern Division, among the enginemen (the only competent authority) gave the following result: "A train of 35 or 40 cars *when reaching over two curves* (the 10° curve at Passaic is reversed) will pull as hard as at any other point on the division, some of the enginemen say: but trains are made up with reference to the 60-feet grades, and I believe an engine will stall with a heavy train sooner on the latter than at Passaic. But the difference in power required is slight."

sought in every direction, by personal investigation and experiment, before driving a stake; and if we may suppose that—with the greater facilities the designers would certainly have and the greater ability they might easily have—they would have reached substantially the same conclusions as those which the writer has reached with labor and difficulty and embodied in Table M; this sliding scale would have been about as shown in Table N, on the preceding page.

Possibly intelligent investigation would show that, if the cost were but trifling, it might be advisable to keep more entirely on the safe side by slightly modifying this table at either end, as shown in the latter columns; but it is to be remembered that it is in no way more important to have the limiting effect of the combinations at the top and bottom of the table less than that of the combinations in the middle of the table than *vice versa.*

Now such a scale as this, wisely and intelligently used, would have given to the line an almost marvelous flexibility. When we encountered a sharp spur or a deep gully, we could use the combinations at the *bottom* of the list, and swing around it with light work: where tangents or easy curvature did not cost much, we could use those at the *top* of the list, and thus run down rapidly to our crossings and run up rapidly over our tunnels. If we attempt to keep to *any one of them exclusively* we have our hands full at once; but by passing in this way from one to another we could reduce almost any line through the roughest country to very light work if it were a line of light traffic, or adapt it to such a standard as its traffic justified. Why should we not do this? It requires judgment and knowledge and skill doubtless to do so without blundering, and much more time devoted to surveys; but is there any other sound objection? All of the above 17 combinations are precisely equivalent in limiting effect, and any difference in the inherent cost of each is so absolutely trifling as to be unworthy of mention;—although not therefore *unworthy of consideration,* in adjusting the detailed alignment. We have entered into those questions too fully to have our meaning mistaken. The effect, however, of a very considerable addition to the number of degrees of curvature or feet of rise and fall *which have no limiting effect* is comparatively small. Yet out of the whole seventeen the Cincinnati Southern Railway pitched upon *one,*—why that one in particular it would be hard to say—and forbade the use of any other of its *precise equivalents,* however great the economy which might thereby be effected. If location were as carefully studied as bridge-building, this would be thought to indicate almost the last extreme of ignorance, like making every bar in a truss of equal strength. Suppose some plain country farmer should find that his team could just draw him up a steep hill through mud a foot deep, and should forthwith draw two conclusions: that it could not draw him up any steeper hill *without any mud*, nor through any deeper mud *without any hill;* should we not write that man down an ass? Yet this is precisely what has been done on the railway in question (and many others); and that, too, when there were 12,522,627.2 good reasons for thinking the problem out carefully —if it can be called a problem—while our farmer would be lucky if he only had one. The only *advantage* derived from this cast-iron rule is, that the unskillful trustees fancy they have a line which they have not. It sounds very much prettier to talk of 60 feet and 6° maximums than of 80 feet and 12° maximums. Yet the latter is what they have *in effect*, and the operating value of the line is no greater by a penny's worth than if they had them in fact. For they may to-day increase any one of their 60-feet grades on a tangent to 80 feet per mile, or sharpen up any one of their 6° curves on a level into a 12° curve, and they will not have affected in the slightest degree the operating value of the line. If there were any slight difference in rail wear, etc., in the latter case, or in the effect on passenger traffic in the former case, it would be so ridiculously trivial as to be unworthy of mention.

Now, if this be so, it becomes of importance to remember that the effect upon the COST OF CONSTRUCTION of such standards is calamitous in a high degree. The precise extent and limits of this disadvantage is, of course, an essentially indeterminate problem, nor has the writer space in which to prove it at length, even if he had the detailed data required. What momentous changes might have been effected in the general route under such a rational and scientific system of inter-adjustment; what short cuts might have become feasible which were wholly impossible under the Procrustean standard adopted; whether an important reduction in the equivalent ruling grade might not have been effected by using say 60 feet and 10° maxima instead of 80 feet and 12°—all these questions we cannot enter into in any way. But it is believed that no one familiar with railway construction in mountainous and difficult regions will question for a moment that *if* we may use such a graduated scale as that suggested, the cost of construction might be reduced at least 25 per cent. without deviating more than 600 or 800 feet from the present line at any point; after deducting from the economy effected, the capitalized cost of any difference in distance, curvature, and rise and fall.[‡‡] If this be so, the cost of the railway in question has been needlessly increased over $3,000,000 by error in the detailed alignment; without now questioning the propriety of the general route or system of gradients adopted. We give in a foot note below an approximate estimate of cost and quantities, so that any one familiar with construction can judge of the difficulties of the route under the standard adopted and the probable effect of such a system of location as that suggested.[§§] In the writer's view, the economy effected might very probably have greatly exceeded the percentage above suggested, but the moral which it is designed to draw in no way depends on the *extent* of the saving, nor has he any desire to exaggerate its amount. Grant that it would have been only $1,000,000 in all, was it not worth saving, and *might* it not have been saved? Is it not time that these more important questions should be analyzed with that exact and conscientious precision which is so freely bestowed on the petty details of structures? The economy and lightness of the gossamer-like fabrics which our modern engineers throw across

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[‡‡] According to the tables we have previously given, the capitalized cost of any increase in these items was as follows, at $1.25 per train mile:

Distance, per foot, by Table A, $0.92 per estimated daily train.
Curvature, per degree, by Table B, $4.35 per estimated daily train.
Rise and Fall, per foot, by Table C, $37.14 per estimated daily train.
On the other hand, the value per foot of any reduction in the rate of ruling grade was (by Table E) $6,686 per estimated daily train.

[§§] The total length of the Cincinnati Southern Railway is 336 miles, and the estimated or actual cost, in round figures, as follows:

Grading....................	$7,000,000,	or about	$20,700	per mile.
Tunnelling (over 5 miles in all).....................	800,000,	" "	2,400	" "
Truss bridges (over 2 miles) about.....................	1,100,000,	" "	3,300	" "
Iron viaducts (nearly 3 miles) about..............	1,100,000,	" "	3,300	" "
Masonry....................	2,500,000,	" "	7,400	" "
Total..................	$12,500,000,	" "	$37,100	" "

The quantities per mile at average prices were:
Grading, 138,000 cu. yds. earth at 15c., *or* 23,000 cu. yds. solid rock @ 90c.
Tunnelling, 79 + lin. feet @ $31.
Truss bridges, 33 lin. feet.
Iron viaducts, 46 lin. feet.
Masonry, 740 cu. yds. @ $10.
That portion of the line, however, which we have been especially considering greatly exceeded this average: 25 out of 27 tunnels were concentrated upon it.

great spans are by no means secured by making them poor and weak; but they are possible because every part of the structure has been made a separate study, and is proportioned with scientific precision to sustain *exactly* its proportion of load *and no more than that*. In this way it is entirely possible to build both a *good* bridge and a *cheap* one; but the bungler knows no medium between Montreal and Ashtabula. Just so it is in location. It is also entirely possible to build both a *good* railway and a *cheap* one, in spite of all ordinary difficulties such as were encountered by the railway in question. The great cost of such railways is on account of *bad design*. An enormous expenditure is incurred for purposes which are wholly unnecessary and subserve no useful end, as in the case of the tubular bridge. But the difference between location and bridge-building is that the errors of location are ten times as costly, are the rule instead of the exception, and—to any one who will look into the subject carefully—are ten times as gross and inexcusable.

THE COST OF EXCEEDING THE LIMITING POINT OF CURVATURE.

We here touch upon an intricate question—one of the most so connected with location. It will be impossible for us to do more than offer a few hints, for any adequate analysis would require a separate paper at least.

It is very obvious that on many railways we *must* use curvature which will limit trains in advance of gradients; and, even when we can manage to avoid it, we are in no case justified in doing so without a careful estimate of the extent of the operating economy effected by so doing.

As a general rule, however, there will be no necessity of introducing curvature so sharp as to have a limiting effect on trains if the ruling grade on tangents be over 40 or 50 feet per mile; provided we adopt such a graduated scale of adjustment between grades and curvature as we have already suggested (Table N); for we may then use very sharp curves, if necessary, by reducing grades to a level. For lower ruling grades on tangents, however, the use of limiting curvature is, as a rule, entirely unavoidable.

In such cases, we are to remember that Table M has been carefully kept within limits where there was *certainly* no limiting effect from curvature. But we are not justified in incurring much expense till we are certain there *is* a limiting effect; and this point of *certainty* would not be until we exceeded by one or two degrees the limits indicated by Table M.

When we are clearly exceeding the limiting point for freight trains, however, we shall not reach the limiting point for passenger trains till we introduce curves sharper by 1° or 2°. For passenger trains are always run at high speed, with ample motive power, and have a relatively low coefficient of curve resistance, which is in no danger of mounting up on them from low speed and insufficient motive power. Consequently any increase of radii which already exceed the limiting point for passenger trains will have value for freight trains only. On the other hand, in respect to the maximum grade on tangents the case is the other way; there is a certain value in reducing them per passenger train considerably in advance of the point where it has value per freight train. The equivalent straight grade to 60 feet + 6° curves is, for freight trains, about 84 feet; and, for passenger trains, not more than 70 feet. Therefore, if a reduction from 84 to 70 feet would pay *for passenger business only* we are justified in making it.

Again, the point of limiting curvature will vary very much with the balance of traffic. If there is much inequality, there will doubtless be many trains of empty cars; but we are not justified in *incurring expense* to adhere to the corresponding standard of curvature, unless it will be paid for by those trains alone. It is to be remembered, also, that in no case can we expect to have trains of fully loaded cars, even with an evenly balanced traffic. The best which is practically accomplished with such traffic is to average about two-thirds of a load. As the inequality of traffic increases, however, the average carload in the direction of heaviest traffic also increases, until, on the great east-and-west trunk lines, which have a heavy inequality of traffic, there are very few cars going east without a full load.

Finally, the most important consideration of all is the probable weight of engine. This *very greatly* affects the allowable maximum curvature; and for this reason, if no other, the weight of engine to be used should be settled, as near as may be, before beginning location. A simple calculation by the formula used in preparing Table M will show that the equivalent curve on a level to a tangent maximum grade of 30 feet per mile is, for a 10-ton engine (on drivers), a 10° curve; for a 20-ton engine, 7°; for a 30-ton engine, 5°; and for a 40-ton engine, only 3½°. This is a very marked and important difference and is the *main* explanation of the advantage in respect to curvature which narrow-gauge railways undoubtedly have, but their advocates do not comprehend or at least admit the cause of it. It is equally open (in fact more so) to any common-gauge railway of light traffic which will have sense enough to use light engines. There is a far more close and intimate connection between the volume of traffic and the advisable weight of engines than is commonly appreciated: it might almost be said to vary directly with the traffic. Engines can hardly be too heavy for a heavy traffic nor too light for a light traffic, and this question should be decided, after careful and thorough investigation, before the final location is attempted. But to follow up the various economic problems connected with location which this question brings up, we should have to begin a new volume at once; and it is to be feared that possibly it is asking too much of locating engineers that they shall bother their head over the probable weight of engines which will not be running for a year or two after they are paid off and gone.

Granting the proper limit of maximum curvature to have been carefully determined for each class of traffic, after considering all the various details suggested above, the writer would estimate the cost of exceeding this limit as about equivalent, per passenger train per degree of curvature, to an increase of two feet per mile in the ruling grade; and per freight train, to an increase of four feet per mile (or possibly in some cases five feet per mile); without now stopping further to explain or to justify this position. These values may be determined from Table E, page 92, for any grade. Thus, if we wish to estimate how much more an inflexible standard of 60 feet + 6° curves was worth to the Cincinnati Southern Railway than an inflexible standard of 60 feet + 8° curves—without now questioning the propriety of either standard—we should find it—allowing interest at 7 per cent. cost of train-mile $1.25, length of division 93 miles, and the equivalent straight grade to the standard adopted 80 feet per mile—to be worth $12,436 per daily passenger train and $24,872 per daily freight train. Allowing the large business of 11 freight + 3 passenger trains, this would give the required difference in value as $310,900; or, for half that business, $155,450, the latter being the more probable volume of business. Thus we see that, in all probability, an unjustifiable expense was incurred even to keep 8° curves off the 60-feet grades; which illustrates how important it is not to guess at a solution of economic problems.

GENERAL AND CONCLUDING REMARKS.

When a railway is projected—if it be a legitimate enterprise and not a mere speculation—a number of economic problems arise which are not within the legitimate sphere of the engineer's duties, but nevertheless must be settled. The history of the inception of a railway is, in its economic aspects, about as follows: A certain number of men conclude that there is sufficient need of a railway to justify the expenditure of a certain *gross amount* in constructing it. This conclusion is not necessarily expressed in a definite sum in advance, but such a conclusion is in effect reached—although often in a very vague form—whenever it is decided to proceed with construction. It does not by any means necessarily follow that the railway is expected to be a source of *direct profit;* for it may be of the highest value to the community and the investors, and yet may never pay a dollar of dividend. In fact, the great majority of the railways of the world have not been directly profitable, yet how vast beyond calculation have been their benefit.

All these questions may properly be considered by the projectors before deciding on construction; and with them the engineer, *as an engineer,* has nothing whatever to do, beyond furnishing a rough estimate of the cheapest line which can be built between the two termini for the given traffic in view, taking into consideration the given rate of interest on capital for construction. The question whether to *build the line at all* or not is one of mere finance and business judgment, and must be settled by an estimate of the probable cost per mile, gross and net receipts, direct profits, and indirect advantages.

Another question which is outside of the strict line of an engineer's duties is the probable difference in way traffic on different lines, although the question as to just how far this difference affects the value of the alternate alignments is a strictly engineering question of the highest importance.

These questions settled, however, the province of the locating engineer begins. We are now done altogether with the question of probable receipts, profits, aggregate cost, and average cost per mile, and the duty of the locating engineer is to neglect them absolutely and consider only OPERATING EXPENSES; endeavoring so to adjust his alignment that the aggregate of those expenses and the interest on cost of construction shall be the smallest possible. To this end it is imperatively necessary that a most careful and detailed investigation should be made into a number of different questions, which at the best are hard to foresee with any degree of exactness. Among these questions are:

1st. *The probable number of trains daily,* in every class of traffic and on different sections of the line.

2d. *The probable weight of traffic in each direction* for each class of trains and on different sections of the line.

3d. *The probable cost per train mile* for each class of traffic.

These three questions should be determined with great care by the examination of the statistics of neighboring and competing railways; and preferably (if it is designed to make use of the tables in this volume) by determining the probable cost of "line" or "transportation" expenses only, and then estimating the total cost of a train mile as $\frac{100}{70}$ of that amount. Station, terminal and general expenses are the most variable of all the items of operating expense in the first place and are little if any affected by the alignment in the second place.

4th. *The probable receipts per train mile from way traffic* for both passenger and freight trains and on different parts of the line.

5th. *The most advisable weight of engines.* This depends both on the gradients and on the volume of traffic, and has a momentous effect on the cost of construction as well as on operating expenses. The writer has reluctantly neglected to consider it in this volume, although he believes that, with the abundant stores of empyrical knowledge from which we may draw at will, the problem is capable of very exact analysis. Some remarks on this head were made above. The balance should always lean in favor of light engines for light traffic for another reason, viz.: on account of the increase of business which is stimulated by more frequent trains; and by light traffic we mean anything less than 8 or 10 trains daily.

6th. *The greatest length of trains which will be hauled in the daily routine of business.* On this question also we have made some remarks above.

These are the *more important* data, which should *always* be determined separately for every railway, with the greatest care. In addition to those mentioned, a more specialized estimate should be made of the various problems of a more general nature, which we have considered at great length in this volume, to be sure, but, nevertheless, have of necessity determined nothing more than a kind of average.* For example, any important variation in the cost of fuel either way from the average of about 10 per cent. of the operating expenses, will considerably affect the value of the various details of alignment. After such special investigation, however, the intelligent reader will find no difficulty in making the necessary substitutions in the various tables of this volume, without reasoning out the whole process from the beginning.

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* The writer would suggest, however, that any such investigations must be made with great care, and extend over a considerable period of years, to be more trustworthy than those given in this volume.

Another question as to which the locating engineer should have some definite ideas, if only to check the vague visions of his board of directors, is as to the PROBABLE GROWTH OF TRAFFIC IN THE FUTURE, and the justifiable *present* expenditure to provide therefor. It would be absurd to claim that *no* such expenditure should be made, for on many railways in the West for example, the present business is almost *nil;* but as a general rule the excuse of "a rapidly increasing traffic" covereth a multitude of economic sins.

The writer had collected quite a body of statistics bearing on this question, but to analyze them in detail would require a long paper; and his own patience is exhausted, as well as his readers', in the attempt to include in one volume a discussion of all the various problems connected with the economy of alignment. In Table O we give the present justifiable expenditure to save $1 at the end of any given period at any given rate of interest. This fact given, it logically follows that, if we expect our traffic to double in any given time, we may increase our present expenditure by the percentage given in the table. This is undeniably correct *in theory;* in fact, we might enter into further mathematical subtleties, and prove that if the

TABLE O.

SHOWING THE JUSTIFIABLE PRESENT EXPENDITURE TO SAVE $1 AT THE END OF DIFFERENT PERIODS OF TIME.

Rate of interest on capital.	5 years.	10 years.	15 years.	20 years.	25 years.
5 per cent.....	$.783	$.614	$.481	$.377	$.296
6 " "	.748	.558	.417	.312	.232
7 " "	.714	.508	.362	.258	.185
8 " "	.684	.465	.316	.216	.145
10 " "	.621	.385	.240	.147	.092

REMARK.—Other values than those given may be determined as follows: The value of $1, at compound interest for *n* years at *r* per cent.

$$= (1 + r)^n$$

Then, 1 ÷ the value thus obtained (given by inspection in a table of reciprocals) gives the sum which will produce $1, if placed at compound interest for the given period of time.

ratio of growth of business is greater than the rate of interest on capital, the present justifiable expenditure, to provide for such increase of traffic, is *infinite*. But all such speculations are wholly delusive, and even the indications of Table O are of value only as fixing a maximum which should never be exceeded. It is to be remembered, first, that railways are almost always built with borrowed capital, and it is difficult for the average financier to borrow large sums on future expectations; secondly, that we cannot in any case borrow $2,000 per mile as cheaply as $1,000 per mile; and thirdly, and mainly, that the rate of growth in traffic is excessively variable and uncertain. As a deduction from a large body of statistics, the writer would estimate that the growth of traffic will rarely average more than 5 per cent. a year east of the Allegheny Mountains, nor more than 7 to 10 per cent. a year west of them; and this ratio of growth is liable to cease at any time for many years, and at periods when it is particularly inconvenient to pay interest on discounted expectancies. In striking a just balance between all these considerations, and determining their justifiable effect on the alignment, there is abundant room for the exercise of that sound common sense and keen forecast of probabilities which command a ready market in every other field of labor but railway location.

Another consideration which greatly modifies the justifiable present expenditure for the immediate traffic and any expected future increase is when there is a possibility of ADJUSTING THE LINE WITH REFERENCE TO THE CONSTRUCTION OF FUTURE IMPROVEMENTS, WHEN TRAFFIC SHALL JUSTIFY THEM. It is evident that in this case the probable growth of traffic should be estimated in a very different manner from that adopted in considering the problem above. We were then estimating the maximum limit of *present expenditure;* and it was proper that our estimate should be exceedingly conservative, but by building, instead of any given line, A, a cheaper and temporary line, B, with reference to the future construction of a still better line, C, we effect a *present economy*, and in considering the expediency of this course we may properly adopt the largest probable estimate of growth of traffic. If there is any *reasonable chance* that business will increase so fast that at any given time in the future it will be advisable to construct the line, C, then if the present saving effected by building a cheaper line, B, will, at compound interest, outweigh the loss yearly accumulated from operating the cheaper line in the meantime, we shall be justified in adopting it instead of the more costly line

A; and yet it might easily be that, if we had A and B alone to choose from, we should unhesitatingly adopt line A.

The possibility of this course is one of very frequent occurrence on every survey, and it is always advisable, *a priori*, for it tends to prudence and present economy. A theoretically correct solution of the problem is very easily reached. We require only to determine:

1*st.* *The number of trains which will be required to justify the construction of line C*, and the probable number of years within which that traffic may reasonably be expected.

2*d.* *The difference in operating value of lines A and B*, per daily train. This difference, *multiplied by the estimated number of trains at the time when the construction of line C will be advisable, and by the estimated number of years until then*, will give, approximately, the aggregate loss during the given period in operating the cheap line B instead of line A, with compound interest charged upon it. If the rate of interest be the same as the estimated ratio of growth of traffic, it will give it *exactly;* if the rate of interest be *less* than the ratio of growth of traffic (as would usually be the case), it will give somewhat too small a sum; while, if it be greater than the ratio of growth, the amount given will be somewhat too large; but the differences are not very important.

3*d.* We require to determine *the difference in cost of construction between lines A and B*, as determined from the comparative surveys, and also the amount of this difference at the end of the given number of years, compounded at a rate of interest representing the fair value of money to the company. The formula for this computation is given beneath Table O.

These few and simple data determined, the problem is solved. If the latter sum exceeds that determined above it, the construction of the cheap and temporary line is probably advisable; otherwise, not. There can, of course, be no approach to certainty in estimates based wholly on a guess at the probable course of future events; but the more difficult it is to reach absolute correctness the greater need we have of *some* guide which shall reduce the unavoidable guesswork to its lowest terms, and save us from the confusion worse confounded which results from not only guessing at facts but at the effect of those facts. The *system* of location here under consideration, viz., a cheap line for present necessities, located, nevertheless, with especial reference to convenience and economy in future improvements, is almost always the truest economy wherever practicable, and highly conducive to the present and future prosperity of the line; and although we cannot determine the exact balance of advantages with the same degree of certainty as in providing for known requirements, yet we *can* assure ourselves that we are not stepping over the limit in either direction, which gives a certainty of error. Due judgment and caution require that we should do so.

Supposing all these questions to which we have alluded to have been thoroughly investigated and decided,—and for any important railway they might well occupy a year's time of an able and competent investigator—the engineer who follows the method of this book will then be able to condense all his data into a nutshell, by drawing up a pocket-memorandum for the guidance of location, in something like the following form:

TABLE P.

GIVING A SYNOPSIS OF NECESSARY DATA FOR THE CORRECT CONDUCT OF LOCATION.

Preliminary Estimate of probable rate of maximum grade:

Going East, ... feet per mile
" West, ... " " "

(Selecting those grades which, by a rude guess, seem most probable and advantageous as a basis for the guidance of surveys and estimates.)

Assumed weight of Engines:

Freight engines, ... tons gross, ... tons on drivers.
Coal " , ... " " , ... " " "

(See page 190.)

Estimated disproportion in traffic:

Through freight, 1 ton East to .... tons West.
Way " , 1 " " .... " "

Corresponding disproportion in total wt. of trains (freight and cars)

Through freight trains, 1 to ....
Way " " , 1 " ....
Mineral trains , 1 " ....

Corresponding maximum length of average trains:

Through freight trains, ... cars, ... feet total length
Way " " , ... " , ... " " "
ineral " , ... " , ... " " "
Passenger " , ... " , ... " " "

(See page 173 Table XXV.)

Estimated Extent and Character of Train Service on the basis of the above Statistics:

Classes of trains.	No. of each class daily.	Estimated cost per train-mile.		Equiv't No. of trains at $1 per train-mile
		For "Line Expenses" only.	Total of all expenses (p. 193).	
Passenger	....	$...........	$...........	....
Way Freight......	....	....	....	....
Through Freight.	....	....	....	....
Mineral...........	....	....	....	....
Totals	....	....	....	....

Assumed rate of interest on capital, ... per cent.

Estimated Ratio of Increase in Traffic:

Minimum probable ratio, for estimates which involve an *increase* in present expenditure, ... per cent. per year.

Maximum probable ratio, for estimates with reference to adjusting the line for future improvements, involving a *decrease* in present expenditure, ... per cent. per year.

(See pages 194 and 195.)

VALUATION OF DISTANCE.

One mile or less, $...... per mile; $......per foot.
From 2 ± to 5 ± miles, $...... " " $...... " "
From 5 ± to 20 ± miles, $...... " " $...... " "
From 20 ± miles, $...... " " $...... " "

(See Table A., page 27.)

(From these values are to be deducted a certain proportion or the whole of the following:)

Capitalized value of the estimated gross yearly receipts per mile (or per foot) *from that portion of way traffic the receipts from which vary directly with the distance hauled.* $...... per mile; $...... per foot.

(See page 28.)

VALUATION OF CURVATURE.

In 2° curves or less, $.... per degree, more or less, in the curve.

In 2° to 8° ± curves, $.... per degree, more or less, in the curve.

In 8° to —° curves, $.... per degree, more or less, in the curve.

(See Table B, Page 43.)

(The writer's own personal view is that these valuations are independent of radius, at least for all curves of less than 8° or 10°; always provided that the *limiting point* of curvature be not exceeded, and that all curves sharper than 2° be properly eased off at the tangent points—as all curves should be—in a manner which it would be foreign to the purpose of this volume to discuss. See page 170.)

Value of avoiding a curve altogether = [No. of degrees in curve + degree of curve × 4] × valuation of 1°, as determined above.

(This rule is offered as a fair estimate. It assumes that the cost of the curve (whether it be long or short) extends 200 feet beyond the tangent points.)

Value of lengthening short tangents = Value of the greatest number of degrees of curvature which is covered by the average train standing on the tangent.

(This also is a rule of thumb; but it appears to the writer a very fair rule. The value given for an increase of tangent is greatest in the case of the technical reversed curve, and thence gradually decreases till the tangent is a train length long, when it ceases altogether. For "broken-back curves" (those curving in the same direction and connected by short tangents) the values given may seem high, but in the writer's view none too high. On the other hand, for the technical reversed curve the values given are far too low. In the writer's view such curves should never be introduced on the "open road" under any circumstances—the objection to them being, not the change of direction in itself, which involves no loss of power over a continuous curve to a train in slow motion on a track transversely level; but the abrupt change in cant of track. To taper out this cant properly there should be a tangent at least 50 feet long per degree of curvature—which any good trackman will speedily throw into a gentle curve. By shortening radii such tangents can almost always be obtained, to the great advantage of the line in every way.)

Cost of breaking up long tangents (exceeding two train-lengths) = Cost of 4° of curvature + No. of degrees introduced.

(This rule assumes the curve introduced to be a 1° curve. The writer commends it to the careful thought of those who may have a leaning toward that most prevalent and foolish practice of incurring expense (often considerable expense) for the sake of securing long tangents. The *distance* lost by a considerable swerve in a long tangent is absolutely inconsiderable.)

Preferable Degree of Curvature, all other things being equal, =

$$\frac{50^\circ}{\text{No. of cars in average train.}}$$

(The above rule is the net result of an analysis which the writer intended to give more fully. It is submitted without further comment or justification. The writer is personally convinced that the curve thus indicated is more economical than a longer and flatter one.)

VALUATION OF RISE AND FALL.

On grades of 0.3 per 100 feet, or less, $...... per foot.
" " " 0.3 to 0.5 " " " $...... " "
" " " 0.8 " " " $...... " "

(etc., etc., as in Table C., p. 64.)

Reduction in RATE *of Minor Gradients :*

(A little table may be made up in the form above from the foot-note to Table C.)

Cost of Breaking up Grades :

(A *convex* angle in gradients, if properly rounded off with an easy vertical curve, may be considered as adding little or nothing to operating expenses. The rail-wear diagrams of R. Price Williams (Proc. Inst. Civ. Eng., Vol. XXV., 1866) indicate that the wear is even less than on a straight grade, but this is improbable.

All abrupt *concavities* in gradients increase wear and tear of rail (and hence of rolling stock) *very largely*, as is abundantly well established by any amount of evidence; but if all such angles be properly rounded off with *long and easy* vertical curves, the increased wear of rail is too trifling for estimate or consideration. A neglect of this simple, inexpensive and effective precaution is one of the most prevalent and inexcusable of all minor errors in railway location.

No change in rate of grade exceeding 0.1 per station is ever necessary, nor should it be permitted.*)

VALUE OF REDUCING THE RULING GRADES.

Advisable balance of ruling grades:

Grades assumed above as practicable,

	say 40 ft. per m. going E.	& 60 ft. per m. going W.
Bal'nce for through fr't traffic..	40 " " "	& — " " "
	or	
	— " " "	& 60 " " "
" " way " "	40 " " "	& — " " "
	or	
	— " " "	& 60 " " "
" " mineral " "	40 " " "	& — " " "
	or	
	— " " "	& 60 " " "
" " pass'ger " "	40 " " "	& 40 " " "
	or	
	60 " " "	& 60 " " "

(See Table G, page 110).

Value of reducing each of the assumed ruling grades, for each class of traffic:

	Going E. (40 ft. per m.)	Going W. (60 ft. per m.)
For passenger traffic................		$.............
" through freight traffic...........	$............	or $.............
" way " "	$............	" $.............
" mineral traffic..................	$............	" $.............
Total value of reducing each rate of grade............................	$............	$.............

(A value for each class of traffic will appear only on one side of the above, WHICH side is shown by the advisable balance of ruling grades. See Tables E and F, pages 92 and 94; also pages 93 and 96.)

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* Nothing is easier than to fudge in a vertical curve off hand while writing down the grades, as follows:

1*st. Make the length of each tangent in stations = half the difference in rate of grade in tenths.* This gives us the two tangent points of the curve.

2*d. Beginning at the first full station inside of either tangent-point* (it does not matter exactly where), *decrease the* RATE *of grade to that station from the preceding by* .05. *Decrease this rate of grade by* 0.1, *successively between each of the succeeding stations.*

This process will fetch us around into the other grade at the other tangent-point at the proper elevation; with the exception that the *whole* curve will occasionally be from 0.01 to 0.04 lower than theory requires. This error results from the neglect of fractional stations, and is wholly unimportant, as well as easily avoided.

3*d*. The middle ordinate on such curves is always 0.025.

For the benefit of those who fancy that the radius of a 1° curve is 5729.65 feet, the writer will add that the curve given by this rule is a true parabola, and not some common curve, unworthy of a scientific man. It might more properly, however, be called the *trackman's* curve, for it will always be one which the locomotive will ride over without knowing it.

Limit of maximum curvature permissable on a level, with a certainty of no limiting effect on trains :

For mineral trains........ ° curves.
" freight " .... ° "
" passenger " .... ° "
(See Table M, p. 176.)

Cost of exceeding the limiting point of curvature :

For mineral trains, $....per degree of curve sharper than..° curves.
" freight " $.... " " " " " ..° "
" passenger " $.... " " " " " ..° "
(See page 190.)

Graduated scale of adjustment between ruling grades and curvature :

(In the form set forth in Table N, page 185; modified according to the limits adopted.)

ASSISTANT ENGINE SERVICE.[*]

Capitalized cost for passenger traffic, $........ per mile of grade worked with assistant engines.

Capitalized cost for freight traffic, $........ per mile of grade worked with assistant engines.

Capitalized cost for mineral traffic, $........ per mile of grade worked with assistant engines.

(See Table L—1, page 120, also pages 116–119.)

Equivalent grades, if worked with assistant engines, to the given maximum grades:

(See Table K, page 115. These grades can only be determined in the field, as occasion arises. The possibilities of combination are infinite.)

Valuation of curvature } *on grades worked with assistant*
Valuation of Rise and fall } *engines:*

(The valuations of these items may be considered as very nearly doubled by the double number of engines, notwithstanding the fact that the number of cars remains the same. Except for the space required, it might be fully demonstrated, as the writer believes, that this rule is very nearly correct, as is also the similar rule given on page 157. They are not merely short rules of thumb, but are thought to preserve a very accurate balance between various economic considerations.

The addition to the *valuation of distance* is given directly by the cost per mile of assistant engine service above. It will be seen that this valuation also has the effect of doubling the ordinary valuation of distance over the remainder of the line, although the car-service remains the same.)

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[*] The writer would again urge that the question of adjusting grades with a view to the use of assistant engines should *always* be considered, on cheap and low-grade lines as well as on costly and high-grade lines. The advantages are very often enormous, and the counter-balancing disadvantage of loss from engines standing idle is a trifling objection which appeals more strongly to the imagination than the judgment. If we can so adjust our grades that instead of having two engines at work all the time we can have only one of them constantly at work and the other standing idle in the yard, fully manned and with steam blowing through the safety valve, for 9-10 of the time, have we not effected an important economy?

Limit of Minimum Radius on grades worked with assistant engines: ....° curves on a level.

(This limit is evidently different from the limit for the rest of the line. The higher the grade the shorter the permissable radius on a level. By using a "pusher" the train is, in effect, cut in two. The curve required is given by Table M, p. 176.)

Cost of Exceeding the Limiting Point of Curvature:

(This is at least doubled by assistant engines, but it can be rarely or never necessary.)

EQUATING RATIOS.

(An extended list of equating ratios, showing the comparative value of distance, curvature, rise and fall, reduction of ruling grade, assistant engine service, reduction of limiting radii, etc., may be made up from this volume, if the reader chooses to do so, by consulting the index. In the writer's view it is better not to use such ratios at all, giving preference to definite money values).

ESTIMATED PRICES FOR CONSTRUCTION.

Earth excavation,	$........	per cubic yd.
Rock "	$........	" " "
Masonry (of various classes),	$........	" " "
Bridging (" " length, etc.),	$........	" " "
Tunnelling,	$........	" c. y. or lin. ft.
Piling,	$........	lin. ft.
Track and tracklaying,	$........	" " "

etc., etc., etc., etc.

(These prices determined, an enormous amount of labor may be saved by making up a table of deductions from them in such form that *all estimates of quantities may be made directly from them* IN DOLLARS AND CENTS. This method is highly economical of labor, is equally convenient in balancing cuts and fills, gives almost entire immunity from gross error, and (more than all else) instantaneously and inevitably impresses upon the mind of the engineer the *financial effect* of any differences in alignment he may propose and *obliges* him to base his judgment and decisions at every step on the hardpan of financial fact. The *cost* of the work is what we care about in conducting location, and not the amount of it. On construction it is different. Any engineer who will once *try* the experiment of making his surveys and estimates on the dollar basis exclusively will never use any other. It is evident that such values may be reconverted into quantities at any time, as easily as *vice versa*.)

Cost of excavation:

Depth of cut.	Cost per station.	Difference for 1ft.
1 ft..................	$	$ ....
2 "..................	....	....
3 "..................	....	....
4 "..................	....	....
5 "..................	....	....
Etc.	etc.	etc.

(This table should be made out for every foot of center height—it can be made out from any of the tables of quantities in common use, or by separate calculation—and a similar table prepared for each class of material and each different road-bed. If the last column (which varies by a constant difference) be made up first, such tables may be computed in a few minutes. In making up tables for fills an allowance of 10 per cent. should be included for shrinkage.

If the line be so rough that estimates from center-heights only are not sufficiently accurate, Trautwine's diagrams may be used with the tables to reduce to level section, or the diagrams given in the writer's work on the Computation of Earthwork will give quantities in cubic yards or dollars and cents for sections having one, two, three or four surface slopes direct from the field notes. The inconvenience and delay of plotting sections for preliminary estimates is wholly unnecessary, on all but the raggedest cliff work.)

Cost of Culverts :

6 feet arch culverts, $...... × center-height, + $......
10 " " " , $...... × " + $......
3 " box " , $...... × " + $......
etc., etc., etc., for each class of structure.

(Design a culvert of each style proposed under a fill of say 10 feet (from the natural surface) and estimate its cost complete. Determine the cost of lengthening it 3 feet (or 2 feet) if under a fill of 1 foot deeper. This gives us the *first* value above, which varies with the center height. Multiply this sum by 10 and subtract the product from the total cost of the culvert. The algebraic remainder gives the *second* sum above, which is a constant independent of length.

When the culvert is askew or on a side-hill, the center height should first be divided by the cosine of the angle between the axis of the culvert and a vertical plane through the center line, as a sufficiently close approximation.)

Cost of Bridge Piers : $...... + $...... per ft. of height + $...... × height^3.

(Any bridge pier may be resolved into certain parts independent of height: a rectangular solid varying directly with the height, and a pyramid. With piers battered ¼ in. per ft., the last valuation above, at $10 per cubic yard, would be only $0.0103. For a pier 10 feet high this gives $10.30; for a pier 100 feet high, $10,300. The cost of bridge abutments, open culverts, and pile or other foundations may be expressed in general form in precisely the same way.)

Cost of Wooden Trestles :

$...... per lin. foot of trestle at grade line.
+ $...... " " " " " 10 ft. ± below grade line.
+ $...... " " " " " 20 ft. ± " " "
+ etc., etc.

(In any wooden trestle every part of the structure above (and including) the cap, and below (and including the *greater part of*) the sill, is directly as the length of the structure and independent of the height. The cost of these portions of the trestle per lineal foot gives us the first line above. The cost of digging foundations, piling, etc., may or may not be included in it. At a certain distance below the cap, say 10 feet, there is a system of longitudinal, transverse and diagonal ties and sway-braces running the whole length of the structure; also 10 feet of posts and batter-posts and (constructively) a certain addition to the length of the sill. All this may be expressed at so much per lineal foot *on a horizontal line* 10 *feet below the grade line.* This gives us the second line above.

Ten feet further down there is a similar system, nearly duplicating the former, and this gives us the third line. So we may proceed till we have provided for the highest trestles likely to occur on the line.

The length of each of these systems below the grade line should be measured a little short on the profile, to allow for any bents which may extend below one system and not quite down to another. At the bottom of the trestle there will be an irregular area of greater or less extent. To estimate this, sketch in by eye a rectangle 10 feet deep and of equal (or somewhat smaller) area. Any one familiar with the construction of trestles will do this with great accuracy.)

Iron Trestles:

$ .... per horizontal foot on the grade line.

$ .... " " " at intervals of .... feet below the grade line.

(Iron trestles are usually let at so much per foot horizontal and so much per foot vertical. To the price per foot horizontal may or may not be added the cost of masonry pedestals. On the Cincinnati Southern Railroad these pedestals have averaged 1.6 cubic yards per lineal foot and extend from 4 to 8 feet or more above the natural surface. The price per vertical foot is very nearly uniform for all heights. On the Cincinnati Southern Railway the average prices were $25 per foot horizontal and $10 per foot vertical, for 30-feet bents. Adding to the former sum the cost of masonry pedestals, say $15, we should have had:

Per foot horizontal, at grade line, $40.00.
" " at intervals of 10 feet, $3.33.

We see here how little the element of height has to do with the cost of trestles. Singularly enough, it appears to have more effect on the cost per foot horizontal than per foot vertical. An allowance for the effect of height may be made in estimating for the irregular area at the bottom of the trestle-profile. It is to be remembered that the trestle is raised above the natural surface by the height of the pedestals.

The above rules are given merely as an illustration of method. They may be amplified into the utmost desired detail with a very slight amount of labor, for, as they are *general* in form it is only necessary to compute a single type of each class once for all, and the Chinese farce of plodding through identically similar calculations over and over again, is then entirely unnecessary. Although these methods may *seem* rude, they are in reality quite as accurate as, and decidedly more trustworthy than, the most careful separate estimates from location notes; and they do away with all temptation to follow the vicious but not uncommon practice of making surveys first and estimates afterwards. To the prevalence of the latter practice we may trace much of our erroneous and wasteful location. It is everywhere and always wholly unjustifiable; and any one who ever has done it or ever would do it may rest assured that his alignment will not stand the slightest economic analysis. In all but the very roughest county it is easier to make up the estimate than to make up the profile, if the engineer be capable of intelligently using labor-saving methods; and in any region where two or three surface slopes are inadequate, then, *a fortiori*, a computer should accompany the party with no other duty than to keep up the estimates. A careful balance of cost and value should accompany every foot of the survey before it is left behind as complete. All of the above estimations may with decided advantage be graphically expressed on a sheet of cross-section paper, but into that question we will not now enter.)

The above table includes all the data which are required for the correct conduct of location, and (with a few occasional exceptions) nothing beyond that. Any engineer may well devote the labor of several weeks or months to filling it out with care and fidelity ; and any railway of any importance would be repaid many fold for the expenditure of a large sum in an exhaustive preliminary investigation for that purpose.' But if the engineer be disinclined to all this labor, or (more probably) his company be disinclined to pay him for it, he may make a few rough guesses at his localized data and fill up the rest of the blanks from this volume, and still have a *pretty fair* guide. And if he should regard the above table as too extended and detailed for "practical use," even when thus hastily filled up, if he will merely make up from the tables in this volume a few rude approximations to some of the *more important* data tabulated in blank above, and carry them on a card in his pocket-book, it is confidently believed that he will be fairly equipped to make a very decent approximation to the true economy of alignment; or at least will be more likely to avoid falling into those gross errors of judgment which disfigure the alignment of so many railways.

Being thus prepared to make a respectable location, the next thing is to do it. And here we pass beyond the point where this book or any other can be of much service. After all, a book of this kind, however excellent it might be, bears only the same relation to the design of railways than a transit does to the fieldwork: one man will do very good work with a very poor instrument, while another man will do the poorest kind of work with the best instrument ever made. But it is not on record that any man ever made a good survey without even a chain, and in furnishing an instrument of some fashion which may be called relatively good because it is the only one, the writer hopes he may have rendered some real service to an occasional patient reader, and shed some little light on the true economy of location. He has not spared his own labor to do so, but no one can perceive more clearly than himself how far he has fallen short. He can only plead in extenuation at once the necessity and the difficulty of the task he has undertaken; for he does not hesitate to declare his belief—in which he fully believes the reader who has followed him thus far will coincide—that the subject which he has so imperfectly considered is at once the most important, the most intricate, the most neglected, and the least understood of any department of engineering design.

THE END.

APPENDIX.

THE WEAR OF RAILS FROM GRADES AND CURVATURE, AND FROM SUPER-ELEVATION.

Some statistics determined by Mr. Charles Latimer, Chief Engineer of the Atlantic & Great Western Railroad, throw some further light upon this question. These statistics were determined by taking an inside and outside rail from the track on different curves and grades, and determining the wear by weight or computation from section. The observations are not sufficiently extensive for any very exact determination of the question at issue, inasmuch as the fluctuations in wear between different adjacent rails are very great, and at least a dozen or twenty rails per curve would be required to give a fair average; but they are a beginning in the right direction and almost the first of their kind. Table XXIX. below gives some deductions from these statistics, the wear in each case being reduced to a uniform duty of 10,000,000 tons, and assumed to vary in direct proportion with the duty, which with steel rails is doubtless very nearly the case. The actual duty varied from 4,000,0000 to 13,500,000 tons. The fluctuations due to the imperfect average obtainable from a single rail are so great as to forbid any very definite analysis or judgment as to the effect of varying gradients, super-elevation, drainage and other external conditions, although Mr. Latimer has noted them with great care; but even as they stand these statistics teach some valuable lessons and give considerable insight into the law of increased wear on curves. If it be possible to do so, Mr. Latimer would be rendering the profession a service of the highest value and interest if he would continue the effort which he has so well begun by weighing a sufficient number of rails on each curve to determine more precisely the average for each.

The statistics below are arranged, first, in order of the sharpness of the curve, and secondly, in the order of the various grades on which curves of the same radii are situated. Most of the rails were of English steel and had lain in the track from 4½ to 5 years. Variations in this respect, however, can hardly be considered to have greatly modified the wear.*

TABLE XXIX.

Showing the Wear of Steel Rails as Affected by Curvature and Grades,

As determined by Mr. Charles Latimer, Chief Engineer of the Atlantic & Great Western Railroad; the observed rail-wear being reduced to a uniform standard of lbs. per yard per 10,000,000 tons duty.

Statistics of Operating Conditions.					Rail Wear in lbs. per yard per 10,000,000 tons duty.				
Degree of Curve.	Grade on Curve..	Weight of Rail; lbs. per yard...	Super-elevation (6-feet gauge)...	Average Velocity of trains. Miles per hour......	Out-side Rail.	In-side Rail.	Averages.		
							Out-side.	In-side.	Both Rails.
8°	64 ft.	66 lbs	6 in.	23.	5.35	4.05	4.84	3.24	4.04
"	Level	"	7 "	25.	4.32	2.44			
6°	29.5 ft	56	4½ "	23.	3.02	3.58	2.36	2.76	2.56
"	18.5 "	66	4⅕ "	25.	1.39	.92			
"	Level	56	7⅛ "	23.	2.66	3.78			
5°	66 ft.	60.6	2½ "	9.4	3.21	1.03	2.66	1.14	1.90
"	25 "	66	3¾ "	25.	2.11	1.25			
4°	70 ft.	60.6	2 "	9.4	2.12	1.58	2.30	2.75	2.52
"	24 "	66	3 "	25.	2.18	4.16			
"	Level	56	5 "	23.	2.80	....			
3½°	22 ft.	66	2⅝ "	25.	2.11	2.51			
2°	25 ft.	66	1⅜ "	25.	1.52	1.98	1.52	1 98	1.75
tangent	55 ft.	60.6	0 "	9.4	1.64		1.98		1.98
"	35 "	66	" "	23.	1.06				
"	29.5 "	56	" "	23.	3.02				
"	24 "	66	" "	25.	1 32				
"	5 "	66	" "	25.	.86				

Remarks.—The rails were somewhat different in length, but not sufficiently so to greatly modify the wear.

The average velocity was determined by assuming 4 freight to 1 passenger train.

The 66 lb. and 56 lb. rails are of English steel (Ebbu Vale & Dowlais); the 60.6 lb. rails are of American steel, made by Cleveland Rolling Mill Co.

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[*] The writer has received from Mr. Jacob Keene, Roadmaster of the Eastern Division of the Erie Railway, a large body of further statistics bearing on this question, but their correct analysis would require an amount of labor which he is at present unable to bestow upon them. They are much less correct and exact in method than those determined by Mr. Latimer, but have the advantage of giving a wider and longer average.

An examination of this table will teach several important lessons.

First and foremost, we may trace throughout the table how much more damage in pounds of steel abraded per 10,000,000 tons a 60-ton engine will do on a light rail than on a heavy rail.

Secondly, we may see that the grade has an important effect, though our data are inadequate for any exact deductions.

Thirdly, we may conclude, on the whole, that the wear of rail increases appreciably faster than the degree of the curve, although it would seem that the two observations on 8° curves certainly gave excessive results.

Fourthly, we may conclude that an average increased wear of 9 or 10 per cent. per degree of curvature is not far from a correct average, as the writer has already once determined in this volume, from statistics of rail wear on the Erie Railway.

Fifthly, we may observe that the tendency of the natural man is to increase the super-elevation in proportion as the grade on the curve is lower. This is (probably) nothing more than an expression of the fact that the centripetal force created by *obliquity of traction* is an important factor in curve resistance; and as this force decreases with the grade (as was pointed out to the writer by Mr. Albert Fink) an abnormal pressure against the inner rail must be *artificially* created, in order to attain the highly desirable end on which we comment below.

Sixthly, we may observe that, as a rule, the wear of the outer rail is greatest, especially on sharp curves, the rail-wear on easy curves being more nearly uniform. This, as the writer believes, is an invariable accompaniment of all correct practice as to super-elevation. The better class of trackmen are introducing a reform in the excessive super-elevation which has very generally prevailed, but in so far as they fail to recognize this fact, that there *should* be an inequality of wear, they are all destined to be appalled by tangible evidence that their elevation is too low. The fundamental error in the assumption that rail wear should be equal is a non-recognition of the fact that the abrading action on the inside of the outer rail is caused by the slow-moving freight trains, which tend toward the inner rail, quite as much (in absolute amount, although not relatively to weight) as by the fast-moving passenger trains, which tend toward the outer rail. This is so because it is *not the lateral forces proper* which mainly cause this abrasion, but *the tendency of the truck to twist on the center-pin* and thus thrust the front-outer and rear-inner wheel forcibly against the rail, the outer wheel doing the most damage, both from the direction of its motion and because it stands at an appreciable angle to the track. An analysis of the forces acting upon the track will show that this twisting moment is a very powerful force which is and must be always present, and that no coning of the wheels has even a tendency to alleviate it or modify it in the slightest degree unless it be to increase it; nor can the super-elevation do more than *transfer* a small amount of this pressure from the outer to the inner rail, until it becomes ruinously excessive and thus accumulates a great and dangerous pressure against the inner rail (frequently leading to derailment of the front inner wheel) in order to effect a *comparatively slight* decrease in the abrasion on the outer rail. For the latter is mainly due, as already stated, to the position of the wheel and the direction of its motion and not to the excess of pressure against the outer rail. Therefore it may be gravely questioned whether the very common test of correct super-elevation, that the wear on each rail shall be the same, is correct under any circumstances. But granting that it might be well enough in the case of a passenger or freight traffic exclusively, it is, in the writer's view, ruinously erroneous when both classes of traffic are combined. For inasmuch as the outer rail is worn away by *both* classes of trains by a nearly equal absolute amount unless interfered with, and a fast-moving passenger train hardly wears away the inner rail at all, nearly the *whole* rail-wear from the slow-moving freight trains must be thrown against the inner rail by an abnormal pressure to produce equality of wear, the rear-inner wheel having no natural *tendency* to cause very great wear unless the excess of pressure upon it be abnormally great. Therefore when equality of rail-wear is attempted a needlessly excessive pressure must be and is produced against the inner rail, which forces the rear wheel into an unnatural position on the top-inner surface of the rail and produces great flange and journal friction which grievously limits the length of trains;—to no purpose whatever except to *transfer* a part of the rail-wear from the outer rail to the inner rail, where it does not naturally belong. This process is also *more dangerous* than if the natural action of the forces were not interfered with, for the abnormal pressure against the *inner* rail first lets the front inner wheel (which stands away from the rail) drop within the track, and this wheel actually *lifts* the outer wheel oft of and over the outer rail, producing a very deceptive *appearance* of an excessive of centrifugal force. The slower the train be going the more danger, in some respects, of this result, for any centrifugal force helps to counteract the twisting moment and the pressure against the inner rail. Moreover, even if this reasoning as to rail-wear be wholly fallacious, true economy requires that the life of the outer rail should be sacrificed—in so far as it *is* sacrificed and not counterbalanced by longevity of the inner rail—to the vastly more important end of increasing to the uttermost the length of freight trains. This is especially true of curvature on grades. It is by no means to be assumed that the trackman has done his whole duty when he has prolonged the life of his rails to the uttermost limit.

The most forcible objection *against* this course is that a very low super-elevation is dangerous to passenger trains by setting free a great excess of centrifugal force, which causes a still more dangerous and objectionable pressure against the outer rail. To this it may be answered that there is abundant negative evidence that a low elevation is *not* dangerous to passenger trains, while, so far as the writer can ascertain (if wrong he hopes to be corrected) there is no instance on record of a passenger train leaving the track from a low super-elevation, although there *are* instances in plenty of freight trains leaving the track in exactly the way we have described. Excessive centrifugal force increases the pressure against the outer rail indeed, but it also tends to greatly alleviate, if not destroy, the twisting moment of the truck, whenever it becomes anything like equal to the excess of centripetal force which acts upon freight trains. Therefore the writer's view would be that wherever the wear of inner and outer rail is EQUAL *there is proof positive of excessive super-elevation*, at least in the case of all limiting curves; and he would slightly modify the dictum in Mr. Huntington's excellent little manual, as follows: "A responsible roadmaster will notice curves and keep the wear UN-equal on inner and outer rails."

MISCELLANEOUS CORRECTIONS.

I have been favored by Mr. Benj. H. Latrobe with the following letter, which sufficiently explains itself. For the sake of clearness and the greater convenience of the reader, I take the liberty (which I trust Mr. Latrobe will pardon) of inserting my remarks and acknowledgments under each separate topic:

"BALTIMORE, April 11, 1877.

"Mr. ARTHUR M. WELLINGTON, Civ. Eng., Danville, Pa.:

"DEAR SIR: As in your interesting series of articles in the *Railroad Gazette* upon 'The Justifiable Expenditure for Improving the Alignment of Railways,' you refer to some professional statements and opinions in my published reports and other papers upon points connected with the location and construction of railways and with their machinery, it is proper that I should offer some remarks upon them of an explanatory character.

"1. In quoting me as putting the frictional resistance of cars at 12 lbs. per ton (of 2,000 lbs.) you would appear not to have noticed that I included that from *curvature*, which, upon the part of the Portland & Ogdensburg Railroad then referred to, had an extreme radius of 637 feet. Estimating, as I did, the increased resistance due to this curve at 50 per cent. of that upon a straight line, the friction upon the latter would be but 8 lbs. per ton, which I believe is about the rate usually assumed for cars in good order."

In respect to this matter, I criticised the assumption of so high a rolling friction (page 76) not forgetting the resistance of curvature, as Mr. Latrobe suggests, but under the impression that the sharpest curves on the ruling grades of the Portland & Ogdensburg R.R. were 6° curves. This impression I derived from some part of Vose's "Manual for Railroad Engineers" to which I cannot now refer, and I have since, through Mr. Latrobe, ascertained it to be correct. Nevertheless, at the time of Mr. Latrobe's estimate it was *anticipated*, as it appears, that sharper curvature might be required on the ruling grades, and he very properly and prudently assumed them in his calculations. A correction is therefore due to him; and yet, as he is quoted on page 510 of Vose's "Manual," his high authority would be apt, in my judgment, to lead the student of engineering into erroneous views. Mr. Latrobe continues:

> "2. In allowing an adhesion of *one-seventh*, in considering the question of the grades of that road through the Crawford Notch pass of the White Mountains, I had in view the effect of the climate of that region with the ice and snow of its winter and the moisture of its summer. On referring to the calculations made in that connection, I found that I had at first assumed a *sixth*, which on reflection I altered to the lower ratio from a wish not to overstate the effective work of locomotives upon the high grades of which I was then treating. I was of course aware that much higher adhesions had been realized upon the railways of the country and would often be upon the one about which I was writing."

On page 78 I claimed that ⅕ instead of ⅐ was the proper ratio to assume in adjusting grades, because it appears to be the almost universal ratio to which the customary weight of trains is unconsciously adjusted. The line in question, however, has a peculiarly unfavorable climate, and if it would be proper to assume a higher ratio on *any* line, it would be on the one in question; but I have little doubt that on that line also the ⅕ is the *governing* or *average* ratio of adhesion, and, if so, that ratio and not the mimimum would seem to be the proper standard for adjusting grades. My authority in this case also, however, was Vose's "Manual," page 510, as already referred to, and on referring to the complete report (Fourth Annual Report, Por land & Ogdensburg Railroad, page 31), from which the extracts there given were abridged, I find that the abridgment has led me to do Mr. Latrobe injustice. It is there apparently implied that the adhesion was assumed for the sole purpose of determining the balance of grades, whereas it was *primarily* for the purpose of illustrating the disadvantages of very high grades (150 and 200 feet per mile) under unfavorable conditions of track. Therefore Mr. Latrobe's assumption is not fairly open to criticism, especially as the ratio of adhesion assumed makes little difference in the balance of grades; and yet I must still maintain that the abridged extract, unexplained, is liable to lead the inexperienced student to erroneous views. Mr. Latrobe's letter concludes as follows:

> "3. While justifying myself upon these two points, I have, at the same time, to admit the commision of an error or two, for which I can account only upon the ground of that human fallibility from which I claim no exemption. I find, upon re-

viewing my calculations of the proper load taken up the grade of 116 feet per mile upon the Southern or Saco side of the Notch summit, that, upon the data assumed as to weight and adhesion of engine and friction of tender and cars, it would have been $156\frac{7}{10}$ tons instead of 170 tons. The computed loads upon the 150 ft. grade of 117 tons and upon the 200 ft. grade of 77½ tons are right within a fraction. I have a more serious error to concede in regard to the comparison of the grades suitable to the two sides of the summit, which, for that of 116 ft. ascending westward should have been 77.6 instead of 63 ft. per mile; for the grade of 150 ft. westward 105.6 eastward instead of 93 ft., and for the grade of 200 ft. westward 150.2 instead of 139 ft. eastward. This error was the result of my assuming the freight in the westward bound train at a *sixth* of the gross weight of train going in that direction instead of a *fourth*, whereas it was a *sixth* of the gross weight of the *east*-bound train. I presume that these errors were the 'obvious' ones referred to in your article. Whether they were observed by any reader but yourself, I have no means of judging, but I am not the less obliged to you for putting me upon the scent to discover them, and having found them by revising my work, I am in duty bound to confess and correct them. I am happy to say, indeed, that they were harmless as far as the interests of the Portland & Ogdensburg Company are concerned, to whom my advice was given. If you will have this statement inserted in the *Railroad Gazette*, as understood in our previous correspondence upon the subject, it will, I hope, set the matter to rights.

"Yours truly,

BENJ. H. LATROBE."

The loads which Mr. Latrobe gives, in the first part of the above paragraph, as 156.7, 117, and 77.5 tons, I have given (page 104) as 149.5, 109.4, and 71.75 tons. These differences arise from an error of my own (running through several articles, but, fortunately for me, not very serious) which I have at last been given grace to see. I assumed that so much of the engine friction as would exist if it were a dead engine with disconnected wheels (approximately the same per ton as car friction) is a tax upon the adhesion of the engine when it is self-propelling, and thus detracts from the paying load. This plausible view is wholly erroneous. So much of the so-called "rolling friction" as arises from *journal* friction is internal to the locomotive, and although it consumes power does not tax the adhesion. The rolling friction proper (that between the wheels and the rails) is the only tax on the adhesion, and Mr. Latrobe informs me that early experiments of Mr. Jonathan Knight, the first Chief Engineer of the Baltimore & Ohio Railroad (a summary of which was published by Mr. Latrobe in the *Railroad Gazette* for April 7, 1876), indicate that this latter resistance contributes not more than ⅛ part of the total. If so, the statement on page 602 of Trautwine's Pocket Book that "8½ lbs. may be assumed as the average car-friction, of which $3\frac{1}{2}$ lbs. may be ascribed to rolling and 5 lbs. to axle friction," requires correction.[*]

The grades which, in the latter part of the above letter, Mr. Latrobe gives as 77.6, 105.6 and 150 2 feet per mile, I have given (page 104) as 78.3, 106.8, 152.0 feet per mile, the fractional differences being due to my error above acknowledged. The same error causes all the grades given in my tables for the adjustment of grades (Tables G and K, pp. 110 and 115) to be too high by about the same amount, viz., 2 feet per mile as a maximum and less than 1 foot per mile for ordinary grades.

I owe Mr. Latrobe a further retraction and apology in having stated (page 78) that the ruling grade, coming east, of the Portland & Ogdensburg Railroad was in fact reduced to 63 feet per mile, thus causing needless expense. So far was this from the fact that, instead of being 63 and 116 feet, or 78 and 116 feet, the ruling grades are 104 and 116 feet, for an inequality of traffic of 3 to 1. My error lay in a too hasty deduction from Professor Vose's statement ("Manual for Railroad Engineers," page 57) that "*guided by the considerations submitted by Mr. Latrobe*, the final location was, with great skill and the utmost patience, *pushed to a most successful completion*." I was unable to interpret this language as meaning anything less than a result substantially in accordance with the eminently sound principles laid down in Mr. Latrobe's report. It would appear, however, that the "most successful completion" lay in the attainment of an *average* gradient on the western slope somewhere near that recommended. This being so, I cannot but regard Professor Vose's pronounced approval, in a text-book for the guidance of students, as decidedly too enthusiastic; but this is little excuse for my hasty assumption, which, even if correct, was unnecessary to my argument and therefore better omitted. I may be allowed to add that I was less struck by the fact that any one man should fall into chance errors from which the ablest are no more exempt than others, than that such errors should escape detection during the construction of the road and during numerous subsequent citations. This consideration led me to speak of them as "obvious," which is perhaps too strong an expression.

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[*] In this connection I would note that the "Table of Journal or Axle Friction," given on p. 601 of Trautwine, is evidently defective. The co-efficient of friction of wrought iron on brass with continuous lubrication is given as 0.054. Testing this, we find that an average rolling friction of 6 lbs. per ton is frequently realized in cars (as a recent authority, see Experiments of L. S. & M. S. R. R., Trans. Am. Soc. Civ. Eng., October, 1876.) Assuming that this is *all* axle friction, it is overcome, with 30-inch wheels and $3\frac{1}{2}$-inch journals, by a leverage of $\frac{30}{3.5}$ and we have as the co-efficient of axle friction $\frac{6}{2000} \times \frac{30}{3.5} = 0.026$, a difference of over 100 per cent. Yet an axle certainly operates under more unfavorable conditions than average shafting. This erroneous table is also given in Haswell, page 350; Molesworth, page 77; Hamilton, page 320, and probably in all the other pocket-books. It came originally from Morin.

I desire also to make a correction in respect to my discussion of alternate routes for the Cincinnati Southern Railway. I have been for some time in correspondence with an engineer now occupying a responsible position of that railway, in whose fairness and impartiality I have entire confidence, and I have become satisfied that (on page 147) I materially under-estimated the cost of the alternate route which I proposed. My error mainly arose from an insufficient allowance for the enthusiastic interest in the enterprise of the author of the "Preliminary Report on Surveys," when I was considering his description of the route in question; and I more especially erred in assuming that the expression "surface work" (which has a technical meaning to me, as, I doubt not, to most of my readers' could not include any *considerable* proportion of classified material. I might, as I think, make my error excusable to fair-minded men, except that I have no disposition to enter into further discussion. The estimate of my correspondent showed a total cost for the Sequatchie valley line (which I proposed) of $4,701,000 as against $7,124,550 on the adopted line, whereas my estimate was only $2,084,000, plus 33 per cent.; but the former was for 30 or 40 feet through-grades (and in one case, for a short distance, 50 feet grades) instead of 20 feet through-grades, which I assumed to be practicable. In respect to gradients, I cannot but believe, after full consideration, that my informant has in great degree fallen into the very common error of assuming that what was not done, because it was not attempted, therefore cannot be done; but, bearing in mind his superior opportunities for obtaining a general knowledge of the ground, it is certainly *possible* that to build the Sequatchie valley line with ruling grades no lower than 30 feet per mile would cost as much as to build the adopted line, and this I will admit. According to my present information, this is the utmost stretch of possibility which is or can be claimed, and, if so, it affects my argument only in degree; but any one who assumes to criticise others has no claim for indulgence when he himself falls into error, and therefore I cannot complain if the acknowledgment of an error of degree shall be assumed to vitiate my entire discussion of the alternate routes in question. It will be but the common fate of any one who seeks to preserve impartial fairness rather than his own reputation for infallibility.

In respect to my suggestion of a possible alternate route down the South Fork of the Cumberland River (page 155,, my correspondent informs me that the indications of that portion of the route which I have personally visited were in fact deceptive, as I suggested might be the case; and that such a route would in fact " encounter insuperable difficulties," as I also suggested. In so far, therefore, as the suggestion carries with it any implication that any oversight might have been committed in that respect, it is wholly unjust and I regret and retract it. It will stand as an illustration of a principle, which was all I intended.

In the introduction to the reprint of my articles (page xv.) I have, while commending the exceptional excellence of the location of the Baltimore & Ohio, Pennsylvania and Erie Railways, stated that " each of them contains grave errors of location, if the writer be competent to judge." I regret that I did not add " in the light of modern knowledge," as more clearly conveying my meaning, although this is plainly implied in the context. In justice to my own good sense I desire to add that the errors I refer to are three : 1st. An imperfect balance of ruling grades for an unequal traffic, from which each of those lines has suffered more or less. 2d. An imperfect inter-adjustment of ruling grades and curvature, which is still, in my judgment, an almost universal source of error and waste. 3d. An inaccurate balance of economic advantages, in some cases, in the adjustment of minor details of alignment. No one of these assumed errors can justly be regarded as derogating from the distinguished abilities of the engineers of these lines, but the point I desire to make is, that it is discreditable to *copy* and *continue in* errors which in the beginning were more than excusable.

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ERRATA.

Page. 2.—Last word, second ¶, for "paper" read "volume."
" 8.—Table IV. take out 131.7, 183.7, 58.3, 326.3.
" 15.—Last two lines Table VII. for "8 and 2" read "68 and 62."
" 20.—Fifth line from bottom for "renewal" read "several."
" 27.—Last line Table A, for one additional "mile" read "foot."
" 27—First line remarks, Table A, for "daily train" read "train mile"
" 39.—Foot note, for "team" read "train."
" 40.—Table XII. last number, for "4,069" read "3,391."
" 43.—Table B, remarks, for "daily train" (1st line) read "train mile."
" 48.—First line formula, for $e : e'$ "$:: d : d'$" read "$:: d' : d$"
" 54.—Nineteenth line, for "lesser" speed read "lower."
" 58.—Fourth line from bottom, for "38,000" read "38,800."
" 67.—Footing to last table, *transpose* 121.14 115.35.
" 74.—Fourth line, "gross loads," for "768" read "798."
" 81.—Opp. 56, for "51.1" read "54.1."
" 86.—First figure, last column, Table D. "1.4." should read "1.3."
" 88.—Bottom take out "(as to which see note &c. p. 433)."
" 96.—First ¶, for "Table D" read "E."
" 99.—Last line text, take out "if not 2¼ or 3 times."
" 102.—Top, for page "442" read "80."
" 107.—For page "457" read page "100."
" 109.—Third line, take out "the."
" 149.—Fourth line, for "higher" read "lighter."
" 158.—Fourth line, for "curvative" read "curvature."
" 161.—Third and tenth lines, for "curvative" read "curvature."

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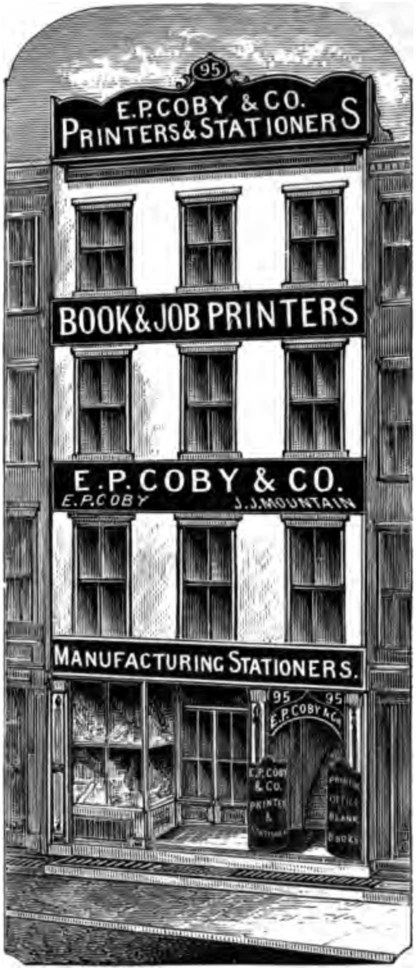

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